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Center for Nondestructive Evaluation: Prospectus

Industry/University Cooperative Research Center, Iowa State University

Donald O. Thompson
Iowa State University

R. Bruce Thompson
Iowa State University, rbthompsonisu@gmail.com

William F. Riley
Iowa State University

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Center for Nondestructive Evaluation: Prospectus

Abstract

This proposal requests a five year operating grant to form a Center for Nondestructive Evaluation (NDE) at Iowa State University. A background section is first given from which it can be concluded that certain barriers need to be overcome in order to provide an improved operating NDE technology in the U. S. with concomitant economic advantages. A plan for the Center is then presented. This plan was developed with input from industry and includes a proposed organizational structure, suggested operating policies, a resource plan, and fiscal and staffing projection for a 6-year period. A detailed research plan is contained in Appendix A. Resumes of project staff and informational materials derived from the formation meeting with industry representatives are contained in Appendixes B & C. Responses from industry are discussed in the introductory letter.

Disciplines

Electrical and Computer Engineering | Materials Science and Engineering | Mechanical Engineering | Structures and Materials



**Center
for
Nondestructive Evaluation**

PROSPECTUS

**Industry/University Cooperative Research Center
Iowa State University**

March, 1985

PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

Cover Page

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NAME OF SUBMITTING ORGANIZATION TO WHICH AWARD SHOULD BE MADE (INCLUDE BRANCH/CAMPUS/OTHER COMPONENTS) Iowa State University-Energy and Mineral Resources Research Institute (EMRRI)					
ADDRESS OF ORGANIZATION (INCLUDE ZIP CODE) Iowa State University, Ames, Iowa 50011					
TITLE OF PROPOSED PROJECT University/Industry Center for NDE					
REQUESTED AMOUNT \$300,000		PROPOSED DURATION 5 years		DESIRED STARTING DATE July 1, 1985	
PI/PD DEPARTMENT Energy and Mineral Resources Research Institute		PI/PD ORGANIZATION Iowa State University		PI/PD PHONE NO. (515) 294-7803	
PI/PD NAME Donald O. Thompson		SOCIAL SECURITY NO.*		SIGNATURE	
ADDITIONAL PI/PD R. Bruce Thompson		SOCIAL SECURITY NO.*		SIGNATURE	
ADDITIONAL PI/PD Wm. F. Riley		SOCIAL SECURITY NO.*		SIGNATURE	
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PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR		AUTHORIZED ORGANIZATIONAL REP.		OTHER ENDORSEMENT (optional)	
NAME Donald. O. Thompson		NAME Richard E. Hasbrook		NAME	
SIGNATURE		SIGNATURE		SIGNATURE	
TITLE Principal Scientist		TITLE Contracts and Grant's Officer		TITLE	
DATE 5/6/85		DATE 5-15-85		DATE	
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NATIONAL SCIENCE FOUNDATION

PROJECT SUMMARY

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NAME OF INSTITUTION (INCLUDE BRANCH/CAMPUS AND SCHOOL OR DIVISION)

Iowa State University
Energy and Mineral Resources Research Institute

ADDRESS (INCLUDE DEPARTMENT)

Energy and Mineral Resources Research Institute
Ames,
IA 50011

PRINCIPAL INVESTIGATOR(S)

Donald O. Thompson, R. B. Thompson, Wm. Riley

TITLE OF PROJECT

University/Industry Center for NDE

TECHNICAL ABSTRACT (LIMIT TO 22 PICA OR 18 ELITE TYPEWRITTEN LINES)

This proposal requests a five year operating grant to form a Center for Nondestructive Evaluation (NDE) at Iowa State University. A background section is first given from which it can be concluded that certain barriers need to be overcome in order to provide an improved operating NDE technology in the U. S. with concomitant economic advantages. A plan for the Center is then presented. This plan was developed with input from industry and includes a proposed organizational structure, suggested operating policies, a resource plan, and fiscal and staffing projection for a 6-year period. A detailed research plan is contained in Appendix A. Resumes of project staff and informational materials derived from the formation meeting with industry representatives are contained in Appendixes B & C. Responses from industry are discussed in the introductory letter.

IOWA STATE UNIVERSITY
of Science and Technology
AMES, IOWA 50011

Energy and Mineral Resources
Research Institute

May 6, 1985

Dr. Alex Schwarzkopf
National Science Foundation
1800 G Street NW
Washington, DC 20550

Dear Dr. Schwarzkopf:

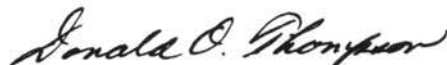
A number of companies have indicated their plans to join the Center for NDE described in this proposal as Industrial Participants. The list includes, but is not limited to:

- | | |
|--------------------------|-------------------------------------|
| - Boeing | - Association of American Railroads |
| - Northrop | - Cummins Diesel |
| - Lockheed | - Deere and Co. |
| - Rockwell International | - Standard Oil of Ohio |
| - General Dynamics | - ARCO |
| - Grumman | - Chrysler Corporation |
| - LTV Aerospace | - Sandia (2) |
| - General Electric | - Westinghouse |
| - Pratt and Whitney | |

Committments for twelve (12) subscriptions at \$35,000 per year have been received at this time; we expect to have 15-20 subscribers by October 11, 1985.

Thank you for your consideration. We are anxious to get the Center started.

Very truly yours,



D. O. Thompson
Program Director
Applied NDE Programs

/ms



**Center
for
Nondestructive Evaluation**

PROSPECTUS

**Industry/University Cooperative Research Center
Iowa State University**

March, 1985

For additional information, contact:

**Donald O. Thompson
Center for Nondestructive Evaluation
215 Applied Sciences Center
Iowa State University
Ames, Iowa 50011 (515) 294-8152**

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ABSTRACT

This Prospectus describes a plan for a Center for Nondestructive Evaluation (NDE) at Iowa State University to be developed under the joint sponsorship of Iowa State University, sponsoring industries, and the National Science Foundation's University/Industry Cooperative Research Center program. A serious attempt has been made to develop a plan that is responsive to industrial needs in NDE; it takes into account both technical needs of industry and new opportunities in NDE, the need for improvement in educational opportunities for NDE engineers in a people-limited technology, and ways to improve technology transfer between academia and industry.

Approximately sixty members from a spectrum of industry have reviewed and critiqued a draft of this Prospectus at a Formation Meeting held in Des Moines, Nov. 19-20, 1984. Comments received at and following the meeting have been incorporated into this Prospectus to the extent possible. It is believed that this Prospectus represents an excellent plan for a Center for NDE that is enhanced considerably by the review process and that offers many real benefits to industrial sponsors.

I. INTRODUCTION

This Prospectus describes a plan for an Industry/University Cooperative Research Center for Nondestructive Evaluation (NDE) at Iowa State University to be established and operated under the joint sponsorship of Iowa State University, sponsoring industries, and the National Science Foundation's University/Industry Cooperative Research Center program. A serious attempt has been made to develop a plan that is responsive to industrial needs in NDE; it takes into account both technical needs of industry and new opportunities in NDE, the need for improvement in educational opportunities for NDE engineers in a people-limited technology, and ways to improve technology transfer between academia and industry.

The Prospectus includes several sections and appendices. Section II is devoted to a background summary of NDE. This summary, together with the analysis of NDE's historic strengths and deficiencies provided therein, sets guidelines for the Center - its objectives, structure, and desired improvements in NDE. Section III provides first a visionary overview of the Center for NDE and a statement of its objectives. Subsections follow in which the Center's initial management, operating, resource, technical, and first year fiscal/staffing plans are given. This section also provides detailed information on the industrial subscription fee (\$35,000) and the rights and privileges of the sponsoring companies. Material in Section III, particularly the management, operational, and resource plans, may be viewed as an initial set of "Bylaws" for the Center. As is noted in this section, however, final Bylaws for the Center will be recommended by founding members of sponsoring industry (cf. Industrial Advisory Board). Section IV provides a summary of the benefits to be expected by both industry and academia from the establishment and operation of the Center and Section V contains information that describes next steps that should be taken by potential industrial sponsors in order to bring the Center into being. Details of the proposed research component of the technical plan and brief resumes of the investigators are contained in Appendices A and B, respectively.

A draft of this Prospectus was presented and reviewed in depth at the Formation Meeting held in Des Moines, Iowa on Nov. 19-20, 1984. The purposes of this meeting were to acquaint interested

industry with the plans for the Center for NDE at Iowa State University and to seek industrial review and critique of the plans. Approximately sixty representatives from interested industry were present at the meeting; a like number of industrial representatives expressed strong interest in the Center, but were unable to be present at the meeting. Review comments obtained from industrial colleagues both at and after the Formation Meeting have been very helpful in refining and focussing the plans described in the draft Prospectus and in the preparation of this Prospectus. Appendix C contains a summary of material from that meeting as well as a copy of a new draft policy statement from the Department of Defense regarding its IR&D program and its favorable attitude toward industry/university interactions of the kind described in this Prospectus.

The authors wish to acknowledge the planning grant support from the NSF University/Industry Cooperative Research Center program in the planning of the Center and preparation of this Prospectus. They also feel indebted to their industrial colleagues for their assistance in providing constructive comments at the Formation Meeting and in their support of the contents contained in the plan.

II. BACKGROUND

The plan for a Center for NDE presented in this Prospectus has been developed to fill pressing industrial needs in NDE and to set a path for the evolution of the technology that will improve significantly the ties between industry and academia in the future. The purpose of this section is to provide a short review of NDE needs and the opportunities for technology and people advances that now exist.

II. A. Needs

A portion of the industrial needs in NDE can be traced, in part, to the fact that there has not existed an active academic counterpart in NDE that extends back for any appreciable time. In contrast to other engineering technologies, NDE was reduced to practice in the United States without the benefit of a cadre of academic people interested in the subject and a firm scientific base derived from an initial period of research and development. It began formally as a need-driven technology during World War II with the establishment of the American Industrial Radiation and X-Ray Society. This organization later evolved into the American Society for Nondestructive Testing (ASNT). Since then, NDE has undergone significant expansion and currently makes use of many techniques other than the original X-ray technology. The major impetus for this growth in technology occurred in response to the needs of the users of high technology products, e.g., the Department of Defense, the National Aeronautics and Space Administration, and the Atomic Energy Commission (now the DOE). However, the major effort in technological improvement and expansion has been confined to a refinement of instruments and equipment used in the manufacturing and maintenance environments. This approach has produced an array of NDE tools and techniques whose capabilities have been demonstrated in several high technology, high-cost programs, but has produced a technology that is deficient in an understanding of phenomena measured and their relation to failure prediction in components and systems.

In parallel with the expansion of operative NDE techniques, relevant research and development activities were being pursued in academic, government, and high technology industrial laboratories.

These developments included work in solid state physics, materials science and engineering, fracture mechanics, electronic device technology, signal processing, and applied mathematics. Despite this parallel growth, relatively little cross-fertilization occurred between the two activities. NDE remained largely tied to the manufacturing and maintenance environments. NDE users did not appreciate the significance of the parallel research advances, and on the other hand, the research community failed to recognize the importance of NDE, the needs of industry, and the applicability of their results to the NDE technology. Colleges and universities, in particular, were negligent in directing educational efforts to support the NDE field.

There is little doubt that the quasi-isolation of industrial NDE from the mainstream of academia has slowed the solution of NDE problems. Recent workshops and meetings have identified a number of technical problem areas that would benefit from improved interaction. These include:

- the need for improved inspection reliability
- an overall need for greater test sensitivity
- an increasing requirement for automated test procedures
- a need to transfer inspection test procedures from one material to another
- a demand for significantly improved calibration standards and procedures with inherent transferability among materials
- a serious need for improved accept/reject criteria or specifications
- a need for better engineered test equipment
- a growing requirement for operators with substantially improved educational backgrounds (as distinct from training backgrounds).

Currently, deficiencies in NDE may be summarized in four categories:

1. Industrial NDE is largely application and/or technique oriented as opposed to failure-initiating phenomenon oriented

This orientation manifests itself primarily in inspection emphasis being placed upon the detection of a flaw by means of a non-quantitative flaw "indication". The non-quantitative nature of an "indication" does not permit a rationally based component failure prediction to be made. This fundamental deficiency has

prohibited the development of realistic accept/reject criteria and carries an economic penalty.

2. Industry alone does not usually possess an adequate research and development base in NDE to establish a phenomenon oriented NDE technology

Research and development in NDE is highly interdisciplinary and requires the collaborative skills of people with backgrounds in solid state physics, materials sciences, mechanics, electrical engineering, mathematics, statistics, etc. who are also aware of industrial problems.

3. Industrial NDE is people-limited and is not adequately supported by educational opportunities at university levels

Although a number of commercial training schools and junior college programs exist, they provide operator training at a technician level, but not at the disciplinary engineering level. Operator training is insufficient to provide a basis for phenomena-based, significant new advances in NDE and for understanding in-depth research literature that has and will continue to be generated in NDE. A gap exists between NDE researchers and practitioners who must reduce the research advances to practice.

4. Technology transfer in NDE needs to be improved

As noted earlier, many advances in other fields as well as research advances in NDE have been made that would be beneficial to the solution of industrial NDE problems. At least a part of this deficiency can be attributed to the lack of industrially based, academically educated NDE engineers.

II. B. Opportunities

As a consequence of important decisions made in the 1960's by high technology government agencies, a major change occurred in NDE research activities. These agencies embraced fracture mechanic design procedures which recognized that all structures were fabricated with inherent flaws. No longer was the traditional "zero" defects policy assumed to be realistic. Instead, the new design procedures recognized the critical flaw size concept, and that failure of structures and products occurred because of large flaws missed in inspection or the growth of small flaws during use cycles. Unfortunately, current NDE techniques used for inspecting structures were incapable

of producing quantitative descriptions of detected flaws that could be used along with the new design practices and new materials, especially those of low fracture toughness. Thus, a new NDE technology was needed to match component and system design practice.

Concern over this deficiency as well as other problems prompted a number of agencies to recommend the initiation of greater research and development in the field. The National Materials Advisory Board in 1969 (1), the Air Force Materials Laboratory and the National Science Foundation in 1973 (2), the National Academies of Science and Engineering (COSMAT) in 1974 (3), and again the NMAB in 1977 all recommended improvements in NDE technology (4). These agencies realized that the cost of maintaining a sufficiently reliable level of performance in major systems was very high and that costs and risks associated with unscheduled system shutdowns could be enormous. In some problem areas, it was concluded that current nondestructive testing technology and procedures were unable to assure the required levels of reliable performance at any cost. In essence, all studies agreed that NDE must have the highest priority for both fundamental and applied research and development.

Perhaps the most comprehensive of the research efforts undertaken was a program funded jointly by the Defense Advanced Research Projects Agency (DARPA) and the Air Force Materials Laboratory in 1974. Although now funded solely by the Materials Laboratory of the Air Force Wright Aeronautical Laboratories, this program marked a turning point in NDE research and is still active at Iowa State University through the Ames Laboratory. A principal objective of this program was to pursue the basic research necessary to create a quantitative NDE technology focussed on a failure prediction capability in which inspection results can be interpreted in terms of appropriate bodies of materials science and engineering knowledge. Other federally sponsored NDE research programs as well as international efforts have adopted the approaches set in the DARPA/AF program so that now the quantitative NDE approach is widely accepted. An additional objective aimed at expanding the NDE research community was also set in that program. That objective has also been met with the result that many more competent researchers are now interested in

NDE than earlier. This was an important step given the quasi-isolation of the industrial/academic communities mentioned earlier.

Two important points can be drawn from the many technical advances that have resulted from the research performed in the last 8-10 years funded largely by the federal agencies:

1. Feasibility of new approaches has been demonstrated for a failure-predictive NDE technology. A few building-block elements of these new approaches include:
 - Models for field-flaw interactions (ultrasonic, eddy current, thermal imaging, etc.)
 - Inverse procedures for flaw sizing
 - Formalisms and procedures to estimate reliability of flaw detection for ultrasonic and eddy current inspection
 - Probabilistic formulations of accept/reject criteria
 - Signal processing routines
2. The new quantitative NDE approaches that have been developed are germane to improved industrial productivity. As noted earlier, these approaches recognize that the attainment of "zero" defects is an unrealizable goal, and provide mechanisms for the setting of accept/reject thresholds based upon critical flaw sizes as described by fracture mechanics. This is new and significantly different from current NDE procedures as practiced by industry. This approach permits managers (or others) to assess risk from a proper probabilistic point of view, and to lay out various costs associated with the production of reliable components quantitatively. In principle, it clearly marks NDE as a desirable, cost-avoidance measure instead of the historic view that NDE is an added cost of production.

II. C. Educational Desires for NDE Engineers

It is well known that mechanisms for improving the educational opportunities for NDE engineers have long been sought. The American Society for Nondestructive Testing (ASNT) has had an educational component to examine this matter, and numerous workshops have been held to discuss the subject. Suggestions have ranged all the way from doing nothing to improve the situation to the establishment of NDE departments within the appropriate academic structure.

It is now generally held that neither of these extremes is desirable. At a recent workshop (ASME, 1983) (5) convened as a part of ASME's series on "Critical Issues in Materials and Mechanical Engineering", a consensus was developed jointly by industrial and academic representatives that the most desirable approach to this problem at this time was a middle-of-the-road approach that would produce NDE engineers with a traditional engineering degree and with an NDE option. Such an option would be multidisciplinary, would contain graduate course work in NDE, and would (in most cases) carry a thesis in NDE.

The above-described approach has several advantages. They are:

- o It takes full advantage of other standard catalogue entries that relate to NDE fundamentals, and requires the introduction of a relatively few new courses
- o It avoids problems with fitting a large number of new courses into the usually-filled engineering curriculum,
- o It provides a basis from which future evolution can readily take place,
- o It is an approach that can be implemented now.

The consensus of industrial and academic opinion supporting the above approach has apparently broadened since the referenced workshop. This strengthening was apparent in another industrial/academic workshop session just held at the Review of Progress in Quantitative NDE, July, 1984 (6). The consensus of opinion at the Formation Meeting in Des Moines was essentially unanimous in this regard.

Iowa State University has, in fact, already initiated this approach through the Engineering Science and Mechanics department; the program is described briefly later in this Prospectus. Student enrollment in the first year techniques course (undergraduate) is up from an initial enrollment of 14 to 160. A new course in the fundamentals of ultrasonics and electromagnetic measurements is now offered at the graduate level, and other offerings are in the planning stage. It has also been possible to obtain additional NDE curriculum improvement by a change in emphasis in existent courses. Signal processing is a case in point. Most importantly, graduate

students from several departments (Engineering Science and Mechanics, Materials Science and Engineering, Aerospace Engineering, Mathematics) are now performing graduate thesis research in NDE. It is expected that this trend will continue and will be further beneficially influenced by the establishment of a Center for NDE. It is evident that graduate engineers who are academically grounded in a major engineering or scientific discipline and with a strong NDE option and thesis will provide industry with a major mechanism for filling the gap between advanced NDE research and industrial implementation.

II. D. NDE Centers in Other Nations

The previous sections describe the wide gap between industrial NDE practice in the U.S. and the status of research. Other nations have addressed this problem and reduced this gap by establishing centers to promote the interaction of academia and industry. It is worthwhile to note that the "best" of such centers are associated with the nations that are either outstripping the U.S. in the high technology market place or with countries with whom the U.S. has had long standing concerns over defense matters. The benefits that have been derived from these NDE Centers cannot be denied. Brief descriptions of known centers are given in the following paragraphs.

Germany has probably the best coordinated and most effective program in advanced and automated NDE technology in the free world. At the two centers of excellence in Saarbrücken and Berlin, government and industry cooperate closely to insure the continuity of individual projects from the basic research to the applications stage. Universities, technical universities, and other higher institutes of learning are government-funded, but politically independent, and teachers and researchers at such institutions have a status similar to that of personnel in the civil service. At these two NDE centers, programs in the whole range of NDE techniques are being pursued with special emphasis on X-ray microradiography and ultrasonic techniques for gas turbine R&D, optical holographic interferometry, acoustic emission, microwaves, eddy current and vibration analysis. Work is also performed to develop NDE equipment with advanced analog hybrid circuit design, other special purpose hybrid circuitry, artificial intelligence communication capabilities, and electromagnetic acoustic transducers.

Many of the German activities are devoted to application of advanced NDE concepts to industrial problems and directed towards optimization and automation procedures.

Japan instituted effective government-university-industry centers in NDE as early as the 1950's. Research is being pursued on a number of techniques such as thermal analysis, real-time tomography, laser scan, soft X-rays and laser holography, but with the main emphasis on applications of some of the more mature methods (such as the use of eddy current and ultrasonic and acoustic emission techniques in the automobile industry for quality control). There is also a newly initiated, coordinated effort among the government, industry, and universities for the development and application of NDE and automated NDE procedures in ordinance and space technology.

The Central Committee of the Communist Party of the Union of Soviet Socialist Republics (U.S.S.R.) made a commitment to develop nondestructive inspection technology in support of development of all Soviet industrial products and current and future weapon production, with special emphasis on advanced aerospace weapon systems. The resources allocated for this commitment go to nine centers of excellence which are devoted to basic research and development and application of advanced manufacturing processes. Three of these institutes, which are individually geared to develop expertise in specialized areas, are in Moscow, and others are located in Leningrad, Novosibirsk, Kiev, and Riga. Generally, 75 percent of their funding is in support of basic research, while approximately 25 percent is allocated for support of industry by delegating institute researchers to assist in the implementation of advanced NDE methods at a number of large industrial complexes. The U.S.S.R. is particularly advanced in the application of eddy current, ultrasonic, radiographic and electric and magnetic NDE techniques for quality control and in the characterization of physical and mechanical properties of materials. The Soviets have also closed the gap with Western nations in acoustic emission. They have strong programs to predict corrosion of parts and systems in service (a problem only partially resolved in the United States), to develop advanced transducers (significant for advanced automatic signal processing, near-surface resolution, and improved defect characterization), to devise and document standards, to develop

basic signal processing algorithms, to develop improved radiation detectors and mechanized systems, and to continue development of radiation sources (protons, neutrons, positrons, and high-energy monochromatic electron beams). There is also strong support for theoretical developments, especially in magnetic testing methods and their applications. The U.S.S.R. lags behind the United States, however, in the development of automated inspection systems, advanced signal processing techniques and fundamental knowledge of field-flaw interactions. In these latter areas, there are strong efforts by the Russians to effect the necessary technology transfer.

England possesses a strong NDE Center at Harwell. This is an excellent research and development center which is funded both by the government and industry. It is well known for services to industry which include a detailed reference library, consulting services, etc. In contrast to the above listed centers, no student education or training is available at this center.

Centers for university-industrial NDE have also been established in Poland, Argentina, and Brazil, apparently with good success. In fact, one of the principal investigators (D. O. Thompson) assisted in the development of the research program for the center in Sao Paulo, Brazil, which operates in conjunction with the Instituto de Pesquisas Technologicas and Brazilian industry.

II. E. Summary

Several conclusions can be drawn from the status descriptions given in this section. They are:

- Interdisciplinary research efforts are needed to develop a quantitative NDE engineering technology and to assist in the solution of difficult NDE problems.
- There is a technological gap between the capabilities of NDE as practiced in industry today and the demonstrated potential for improvement offered by research advances that have been made and will continue to be made.
- There is a significant barrier to the transfer of research advances in NDE from the laboratory to industrial implementation due, in part, to a limitation of people in NDE engineering. This point needs clarification. A number of training schools exist which do a good job in training NDE operators in the

use of the usual inventory of NDE techniques. A few institutions are producing doctoral students who have pursued NDE as thesis topics. However, very few engineers are being graduated with industrially relevant NDE experience and desires and who are capable of reducing new research advances to practice. Industry generally recognizes the need for graduate engineers who possess an academic option in NDE.

- The value of NDE centers for reducing and bridging the gap between academia and industry has been demonstrated in other nations who represent chief economic competition for the U.S. or with whom the U.S. has had concern over defense matters.

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III. PLAN FOR A CENTER FOR NDE

The purpose of this section is to describe a plan for an Industry/University Cooperative Research Center for NDE at Iowa State University. It includes first a visionary description of the Center and a statement of its objectives followed by subsections that give plans for Center management, operating policies including requirements for industrial sponsorship, funding, technical program, and fiscal and staffing plans. These plans may be considered as tentative Bylaws for the Center that are consistent with University policies and industrial desires. These suggested Bylaws will be reviewed, modified if need be, and ratified by the founding Industrial Participants of the Center (cf. III. B). (Details of the research component of the technical plan and brief resumes of investigators are given in Appendices A and B, respectively). Serious attention has been given to the development of a model for the Center that best suits the joint interests of industry and academia described in the previous section. Because of the diversity of requirements placed on NDE, the model selected may, in fact, represent an unique solution. It received essentially unanimous approval at the Formation Meeting in November, 1984. It will become evident in this section that the structure of Iowa State University and the cooperative attitudes that exist within that structure permit the goals of the model to be realized.

III. A. Vision and Objectives of a Center for NDE

Figure 1 shows a schematic representation of the Center for NDE at Iowa State University. First and foremost, the Center must be a place in which forefront research in industrially relevant NDE is pursued by members of the faculty and their students in an interdisciplinary environment. The interdisciplinary environment is key, for problem-oriented NDE research frequently involves a project approach in which publishable, disciplinary advances are made by individual project members that can then be integrated into a project output. This feature is characteristic of the industrial laboratory and largely distinct from the traditional single-investigator approach of the University.

Secondly, the Center would not be a teaching Center; students associated with the Center must be accepted in a graduate degree program in one of the established disciplinary departments and will work under the supervision of the student's major professor. Faculty and students will be drawn from any cooperating department in either the Engineering College or the College of Science and Humanities to perform research in industrially relevant NDE topics. Selection for participation in the Center will be based solely upon the candidate's ability to contribute to the attainment of project research goals and the candidate's career goals. Even though the Center itself is not involved in the teaching function, coordination mechanisms must exist to assist in curriculum development in the established disciplinary departments based on lessons learned with industry in the Center. Students will thus be graduated who are expert in one of the many facets of NDE and who are acquainted with others.

Finally, a Center should provide an environment for direct interaction between faculty and students and qualified industrial supporters of the Center. This feature is considered to be an important element of technology transfer and to the continued development of industry-university relations. These interactions will provide Industrial Participants with insight into problems and will provide strong motivation for faculty and students in better defining their goals.

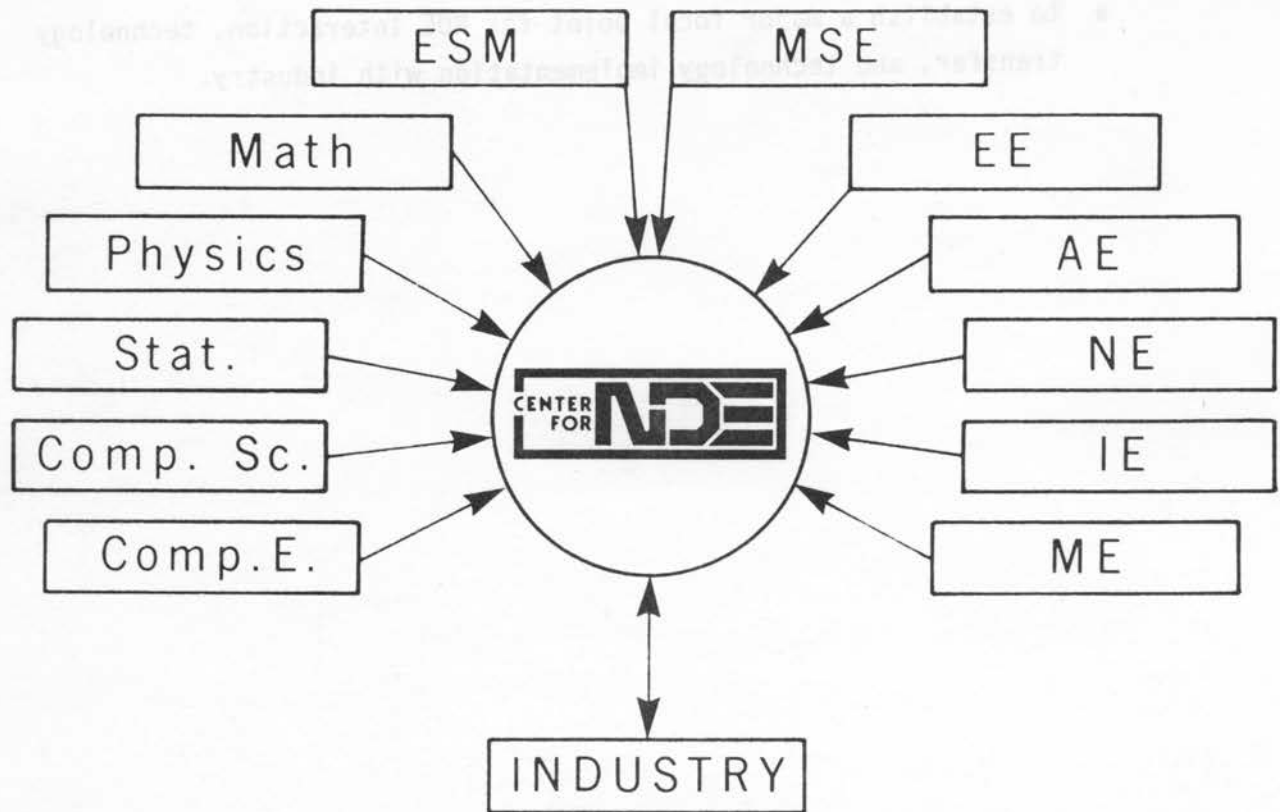


Fig. 1. Model for Center for NDE.

A set of objectives has been formulated for the Center that is consistent with the description given above. Pursuit of these objectives should initiate a focussed action to overcome the perceived deficiencies of NDE described in Section II. They are:

- to pursue research in advanced NDE and materials reliability
- to increase the number of students in graduate degree programs as a consequence of their involvement in NDE research and early contact with industry
- to establish a major focal point for NDE interaction, technology transfer, and technology implementation with industry.



III. B. Management Plan

The position of the Center for NDE within the Iowa State University structure is shown in Fig. 2, a position in keeping with the Center model given earlier. It will be operated as an autonomous unit within the Energy and Minerals Research Institute (EMRRI) and will report administratively to Dr. Robert S. Hansen, Director, EMRRI. Dr. Hansen will serve as facilitator in forming the primary interface between the Center and a number of University and State functions. These include the University's contracting office through which both NSF and industry funds will be channeled, continued interaction with the University's personnel and business offices, contact with the University's legal office which will be important in the development of the Center's industrial relations, and interactions with the Iowa State University Research Foundation (ISURF), which also retains legal and business expertise.

Figure 3 shows the internal management structure of the Center. The roles and responsibilities of each component of the structure are given below.

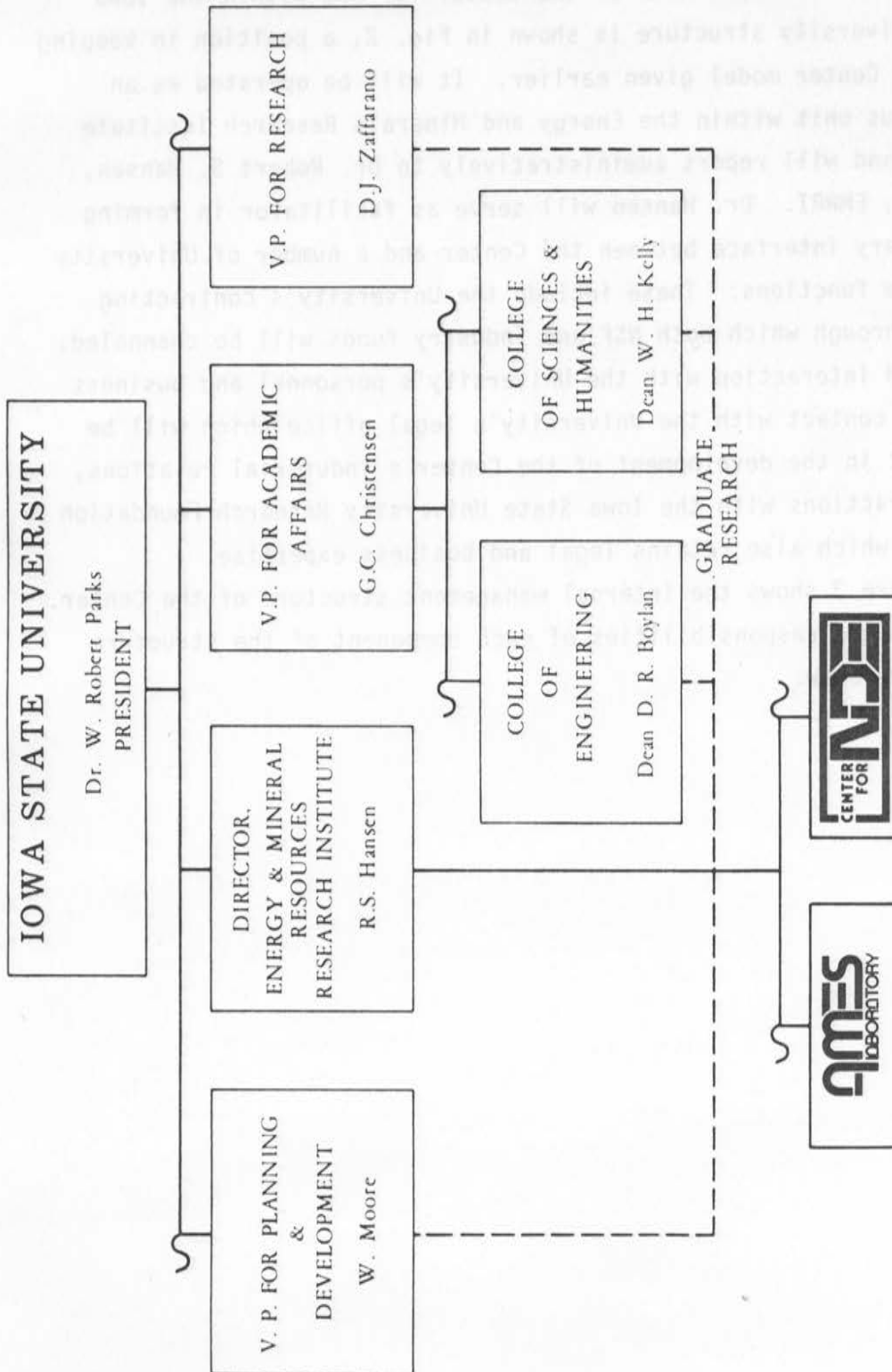


Figure 2. Location of Center for NDE within the structure of Iowa State University.

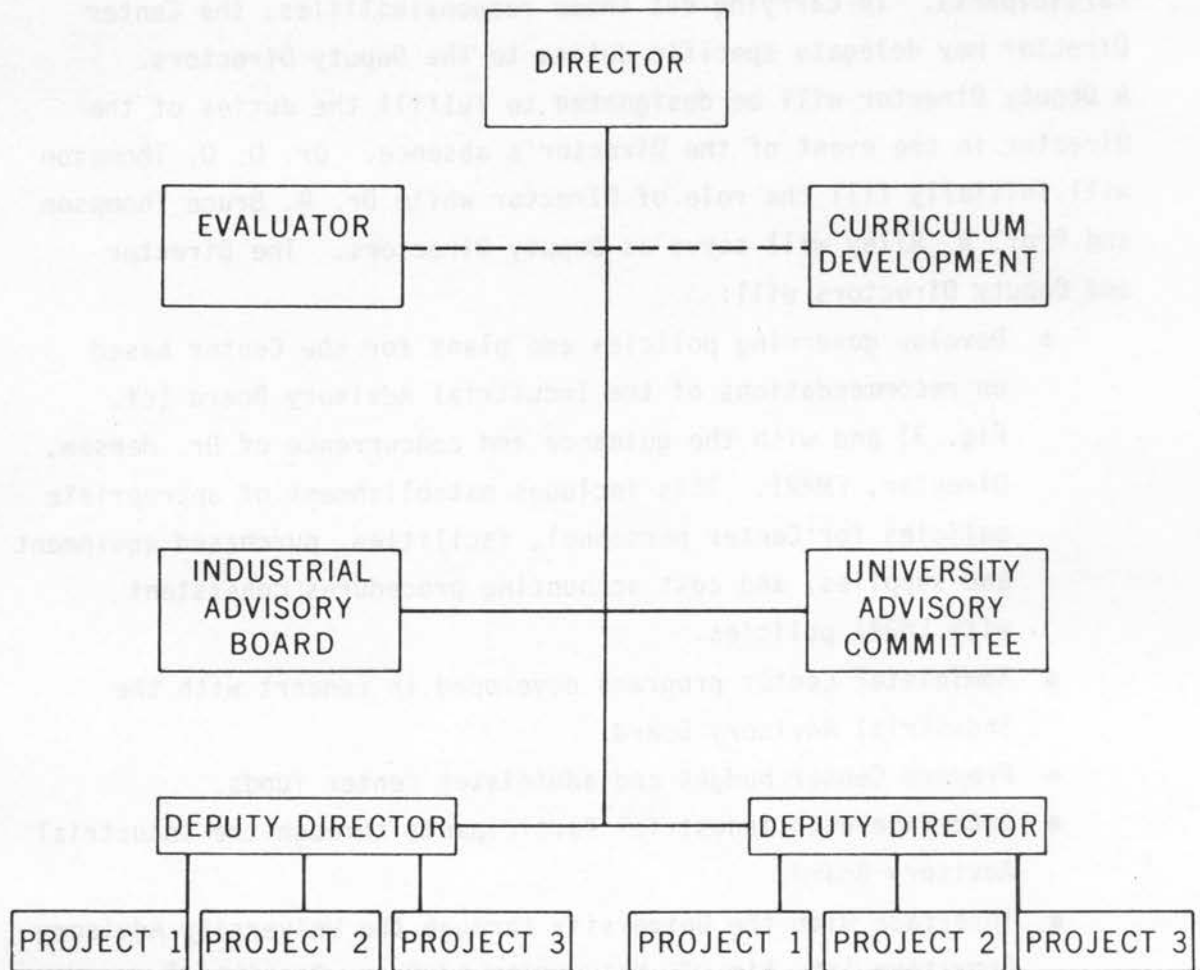


Fig. 3. Organization of Center for NDE.

Center Director and Deputy Directors

The Center's senior management will consist of a Director and two Deputy Directors appointed in accordance with applicable University policies. The Center Director will have primary responsibility for the administration of the Center and interaction with the Industrial Participants. In carrying out these responsibilities, the Center Director may delegate specific duties to the Deputy Directors. A Deputy Director will be designated to fulfill the duties of the Director in the event of the Director's absence. Dr. D. O. Thompson will initially fill the role of Director while Dr. R. Bruce Thompson and Prof. W. Riley will serve as Deputy Directors. The Director and Deputy Directors will:

- Develop governing policies and plans for the Center based on recommendations of the Industrial Advisory Board (cf. Fig. 3) and with the guidance and concurrence of Dr. Hansen, Director, EMRRI. This includes establishment of appropriate policies for Center personnel, facilities, purchased equipment and supplies, and cost accounting procedures consistent with EMRRI policies.
- Administer Center programs developed in concert with the Industrial Advisory Board.
- Prepare Center budget and administer Center funds.
- Interface with Industrial Participants through the Industrial Advisory Board.
- Interface with the University through the University Advisory Committee (cf. Fig. 3, University Advisory Committee).
- Interact with, and provide recommendations to, Curriculum Development (cf. Fig. 3) and other University officials as appropriate.
- Provide assistance to the Center Evaluator.
- Issue Center reports on operations and research as required.
- Participate in Center's research program and serve as faculty advisors for students.

- Develop and maintain liaison with other NSF University/Industry Cooperative Research centers, other organizations with strong NDE interests, e.g., NBS and the EPRI NDE Center, universities that pursue NDE activities, professional societies with interests in NDE, etc.

Industrial Advisory Board

The role of the Industrial Advisory Board (IAB) is to serve as a principal advisory body of the Center. It will provide recommendations covering all Center policies, programs, operating procedures, and budgetary matters. This Board will be the forum through which the ideas, goals, and requirements of the Industrial Participants of the Center are expressed and coordinated. It is anticipated that the IAB will elect a chairperson by majority vote of its members and develop its own internal structure to best fulfill its role.

The membership of the IAB will consist of one voting member representing each Industrial Participant and the Assistant Director of EMRRI (cf. III. C, Operating Policies and Procedures). In addition to these voting members, the National Science Foundation will appoint one non-voting observer. Other non-voting observers may be invited and seated by majority vote of the IAB. The IAB will:

- Recommend Bylaws for the Center for NDE
- Make recommendations on Center policies, programs, procedures, and budgets.
- Set guidelines for intermediate (4-5 years) and longer range research directions including research topics and funding limits.
- Review all research proposals and recommend selection to the Center Director.
- Assist Center management in development of a resource plan to meet Center objectives.
- Review operating and research budgets and recommend changes as deemed necessary.
- Screen and evaluate patent applications generated in the Center and recommend those of potential industrial merit to the Center Director for action by the University.

University Advisory Committee

The role of this Committee is to advise the Center management to ensure that all activities of the Center are consistent with the policies of the University. The Committee will consist of the Associate Director for Science and Technology of EMRRI, the Departmental Executive Officers of the cooperating departments, representatives of the Vice-President for Planning and Development, the Vice-President for Research, and the Deans of the College of Engineering and the College of Science and Humanities. A representative from the Iowa High Technology Council will serve as a non-voting member of this committee.

The Committee will:

- Assure that research projects selected for funding by the Center are in accord with the policies of ISU
- Advise Center management of the impact of Center operations on the resources and facilities of the University
- Disseminate information to others within the University, the community, and the State regarding the activities of the Center
- Provide guidance and access to University resources.

Project Leaders

The purpose of the Project Leaders is the assurance of technical progress and excellence within the projects. Project Leaders will generally be selected from faculty or senior research personnel involved in the Center. Project Leaders are expected to:

- Propose research projects and identify the interdisciplinary resources required to conduct the project
- Organize a project team composed of senior faculty, postdoctoral fellows, graduate students, and Center research staff
- Interact directly with the Industrial Participants
- Publish and patent findings.

Curriculum Development

The purpose of this function is to provide a formal means for discussing and transmitting recommendations from the Center to the University relevant to new curriculum items that would be of value to students pursuing an NDE option. Prof. H. J. Weiss, Head, Department of Engineering Science and Mechanics, will fill this role. This function will not be funded by the Center, but will be maintained by the University. Direct opportunities thus exist for members of the IAB to discuss their views with those with authority to shape curriculum developments.

Evaluator

An individual external to the Center but associated with Iowa State University has been designated by the National Science Foundation (NSF) as the Center Evaluator and will be responsible for the evaluation activities. That person is Dr. Anton J. Netusil, Section Leader, Research and Evaluation Section, Professional Studies Department, College of Education. Dr. Netusil has a broad and extensive range of evaluation activities and is well qualified to serve as the Center Evaluator.

The evaluation of the Center shall be directed toward accomplishing two primary objectives. The first of these is to provide NSF with the requested information in the four (4) areas NSF has designated. The second objective, equally as important as the first, is to provide the Center Director and Deputy Directors with the information they require to make the necessary decisions about the Center and its progress so that the Center can reach its full potential. In order to reach these two objectives, it's envisioned that the Evaluator will play an active role within the Center, and will become known to Center personnel and Committee members. The four designated NSF topics are given below.

1. Documenting Center Development. The purpose of this study area is to develop a comprehensive and comparative picture of the development of each center. The data base will consist primarily of program documents, informal interviews with program staff, and the public record. The result will be a narrative history of each center highlighting the qualitative similarities and differences across the various institutions.

2. Network Analysis of Interaction Patterns. An important objective of the Cooperative Research Center's program is to stimulate interaction between University and Industrial researchers. This study area proposes to determine the actual network of interactions and information transactions among the various participants at each of the centers. The data base will be obtained by questionnaires from Center personnel, and will be subjected to various network analysis techniques. The result will be a sociometric description of the frequency of interactions, the modality of interactions and the technological content of transactions.

3. An Organizational Description of the Center. Each of the centers has independently established an operating organization in order to accomplish its purposes. Each has a structure with its constituent roles, norms, and rewards, yet each center is in some way unique. What is unclear at this time is which are the structures or structural elements most appropriate to achieve the objectives of the centers. This study will provide data for a comparative organizational analysis of each of the centers. Data will be gathered from the administrators and senior researchers at each center, using a structured questionnaire or interview protocol. An organizational profile of each center will be the outcome.

4. Study of Organizational Effectiveness. The primary "success" variable for the Cooperative Research centers is their long-term survival. However, it would be useful to attempt to ascertain intermediate and intervening success (or effectiveness) measures for center operations. One obvious intermediate outcome measure is the nature of research products developed during the course of a given center's lifespan. It would also be useful to determine the responsiveness of the various projects to industry needs and interests. An instrument will be created to assess midstream accomplishment against various effectiveness criteria.

III. C. Center Operating Policies and Procedures

Recommendations for policies and procedures that govern the Center will be provided by the IAB to the Center Director. These recommendations will then be considered by the Director in the formulation of Center Bylaws that are consistent with University policy. An example of a possible set of operating policies and procedures that meets the Center objectives, incorporates industrial comments obtained at the Formation Meeting, and that has been approved by the University, is given in this section.

Membership in Center for NDE

Any corporation or organization may become a sponsor of the Center for NDE consistent with applicable federal and state laws and statutes. A member organization and its designated representative will be called an Industrial Participant of the Center for NDE and will be entitled to share all scientific and engineering benefits provided by the Center. The sponsoring organization will be entitled to one member on the IAB per membership fee.

In order to achieve status as an Industrial Participant, the sponsoring company will provide a three (3) year commitment for support of the Center with an annual fee of \$35,000 which may be paid incrementally. The company is given the right to cancel this commitment upon rendering six (6) months notification to the Center in writing.

Industrial Advisory Board Meeting

Two meetings of the IAB will be scheduled for each year. April and November are recommended unless alternative dates are adopted by the IAB. The meetings will include a presentation of the research accomplishments for the last six months and other items of business as appropriate. The presentations will be made by the Director, Deputy Directors, and faculty and students performing the research.

Each meeting will include:

- a) A review of the research and other Center activities performed during the last six months
- b) A review of the proposed research agenda for the following academic year (primarily April meeting)
- c) Allocation of resources for the following academic year (primarily April)

- d) Any modification of Center Bylaws
- e) Other business as recommended by the IAB members.

Member companies are encouraged to send additional representatives to the technical review meeting. However, the business meetings of the Board will be restricted to the voting members as defined above (cf. III. B, Industrial Advisory Board).

Before the April meeting, the Center Director will prepare a research agenda, including a proposed budget. The Board will review research proposals and recommend approval, rejection, or modification. Project proposals may also be initiated by the Board.

Research Projects

Research projects can be proposed by Project Leaders, prospective Project Leaders, any member of the IAB, and Center management, and submitted to the Center Director. They will then be referred to the IAB for review and ranking according to the Board's priorities. Based on the IAB's recommendations, the Center management will provide final authorization for projects depending on the availability of Center funds. Each funded proposal will be reviewed by the University Advisory Committee for conformance with ISU policies and standards.

It is anticipated that most research projects undertaken by the Center will require a 4-5 year time frame for completion with annual renewals following the process described above.

Reporting

The Center will prepare two reports each year that describe current research results and any other Center activities. One of these will be a mid-year report that summarizes work for the first six months, and the second will be a comprehensive annual report that will include detailed descriptions of progress made. Three copies of the report will be furnished to each Industrial Participant for use in his/her company. The reports and the mid-year progress report described below will be marked Confidential, and will be considered confidential for six months after their release. The reports will be distributed only to member companies during the six-month period following publication.

Publications

The University and the Center reserve the right to publish the results of all cooperative research conducted in the Center. Industrial Participants will, however, receive advance copies of all papers containing the results of the Center research program prior to submission for publication. Industrial Participants will then have the right to request a delay in publication of a paper for a period not to exceed six (6) months from the date of receipt if the Industrial Participant feels that his/her company has justifiable reason for requesting such action. A request for delayed publication must be made in writing to the Center Director within thirty days from the date the proposed publication is mailed to the Industrial Participant; the request must justify the delay. The above considerations do not apply in the case of graduate student theses and dissertations that are submitted directly to the faculty and Graduate College as part of a degree program, but they do apply to papers and reports extracted from the thesis or dissertation intended for open literature publication.

Patent and Software Rights

All patents derived from investigations conceived or first actually reduced to practice in the course of research conducted at the Center will belong to the University; accordingly, the University will pay all costs associated with the procurement and maintenance of such patents. Inventions made with support from the National Science Foundation or other federal agencies will be subject to the provisions of any applicable laws (e.g., PL 98-260). Representatives from the Center management and the IAB will assist the University, if the University desires, in screening possible patent applications emanating from the Center and in selecting, for further action, those that are deemed to have industrial market potential.

The University will grant a royalty-free, non-exclusive license to any Industrial Participant to use any of the patents generated from the Center (so long as internal use within the participating company and its vendors is intended). In the event that all members of the IAB agree that commercialization of a patent by an Industrial Participant is desirable, then that Industrial Participant may seek

and negotiate an exclusive royalty-bearing license from the University for selling the patentable subject matter, subject to the royalty-free licenses held by the other Industrial Participants. If no Industrial Participant wishes or is able to commercialize the patent even though the IAB and Center management believe that step to be in the interest of the NDE field, then companies other than the Industrial Participants will be sought, by the University, to undertake commercialization. It will be the Center's general policy that all patentable subject matter will be patented.

Any royalties generated as a result of patent licensing will be used first to reimburse the University for costs incurred in the procurement and marketing of that particular patent. After those costs have been recovered, royalties will be distributed annually as follows:

1/3 to the inventor or inventors (up to a cumulative total of \$500,000.00 per invention, then 15% thereafter) with the remainder of any annual royalty accrual being divided equally between the Center for NDE and Iowa State University.

Software developed in the Center will also belong to the University. As in the case of patents, the University agrees to make all software available to the Industrial Participants at no cost so long as it is for internal use within the sponsoring companies. If it becomes apparent that commercial versions of selected software packages are desirable, then procedures defined for the patent case will be applied. As in that case, Industrial Participants will be given rights of first refusal to enter into such negotiations. Any revenues that result from the commercialization of software packages will be distributed in the same way as patent royalties.

Industrial Participants who are members of the Center at the time of patent or software disclosure will participate in the rights described above.

Projects Outside the Scope of the Center's Program

Any member company may negotiate a separate contract with Iowa State University and the Center to perform research or other specific services in addition to the cooperative technical program funded by all member companies. For example, a specific Center Industrial

Participant may wish to develop an instrumental prototype for a specific application using concepts developed in the cooperative research program or in other non-proprietary research programs (e.g., those that are federally funded). This development will be considered the sole obligation of the Participant initiating the offer and may carry different confidentiality, patent, or copyright considerations than those of the cooperative research effort.

Consulting Arrangements

Consulting arrangements between sponsoring companies and University faculty are encouraged by the Center, but must comply with normal University procedures. It is suggested that such arrangements be made directly with the faculty member involved.

Informal Communications

Informal meetings can be scheduled by appointment at any time. These meetings are viewed as a primary mechanism for translating research results into assistance for the member companies and obtaining technical information and ideas from the member companies. Informal technical contacts are encouraged at all times.

III. D. Resource Plan, Resource Management, and Status

It is, of course, clear that a Center for NDE at ISU cannot be established without appropriate resources. The presumption has been made that the Center is best developed as a cooperative enterprise between government (NSF) and other agencies, the University (including the State), and sponsoring industry. The purpose of this section is to describe a plan for the procurement of the necessary resources, the management of those resources, a summary of available resources as they currently stand, and resources yet needed.

III.D.1. Funding Sources and Funding Flow

Funding and other resources for the Center for NDE are being sought from four sources. They are Iowa State University, sponsoring industries, the National Science Foundation (and other government agencies), and the Iowa High-Technology Council. Figure 4 shows the current source plan for the various kinds of funding needed and the organizations from which the appropriate funding is being sought.

A schematic diagram that depicts funding flow is shown in Fig. 5. Funds from sponsoring industry, NSF and other agencies, and the Iowa High Technology Council for the Center will enter the University through normal University channels and will be placed in Center accounts within EMRRI. Funding for faculty members and students selected for Center membership will be made available to the individual faculty member utilizing funding procedures already established in EMRRI. Final selection of members will be made by the Center Director with the advice of the IAB. A faculty member's continuance in the Center will also be based upon the continued acceptability of his/her work to the Center Director; the Director's decision to discontinue a Center faculty member would also be made after considering the advice and recommendations of the IAB. This plan should ensure that the Center's work will reflect a viable, forefront research effort that is free to move on a 4-5 year time interval as technology and new opportunities dictate.

	OPERATING	RESEARCH EQUIPMENT	CURRICULUM DEVELOPMENT	FACILITIES
ISU	X	X	X	X
IH-TC		X		
NSF	X			
PARTICIPATING INDUSTRIES	X	X		

Figure 4: Funding source plan

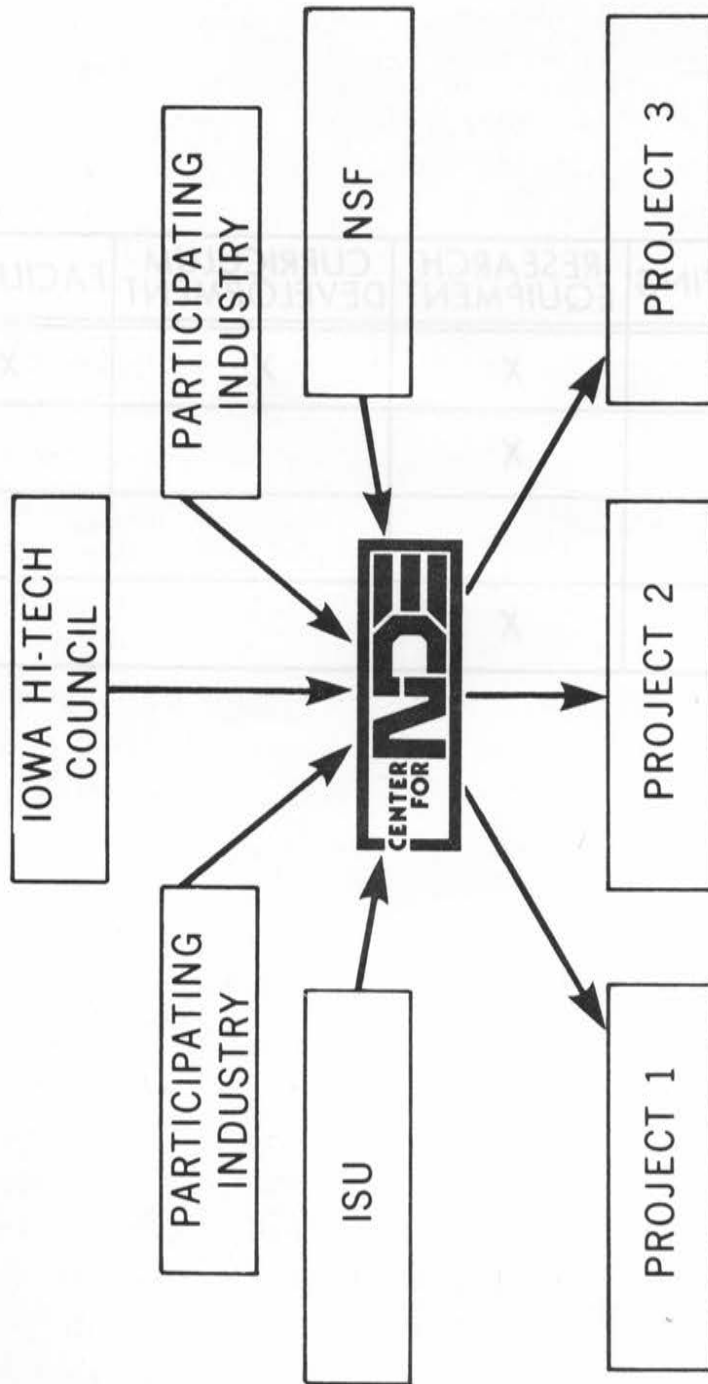


Figure 5: Schematic diagram of funding flow

III.D.2. Resources in Place

Iowa State University

A substantial number of resources have been committed to the development of the Center by Iowa State University in all categories shown in Fig. 4.

A. Operating

The University has agreed to remit overhead on all industrial funds earmarked for the Center for NDE. Remitted monies will be used in the Center for increased faculty and student research and other Center activities recommended by the Industrial Advisory Board.

B. Senior Research Positions in EMRRI

Through EMRRI, the University has agreed to initiate two new senior research positions, one beginning in '85-'86 and the second in '86-'87. These highly desirable positions are continuing appointments that will be used to augment the breadth of the current research staff. High priorities in filling these positions will be given to "world-class" people who are experts in aspects of radiography (e.g., μ -focus, real time image processing, computed tomography), electromagnetic techniques, and instrumental design and engineering strengths. A search has now started to find candidates for a position in radiography.

C. Graduate Fellowships in NDE

1. EMRRI Fellowships

Dr. Hansen, Director, Energy and Minerals Resources Research Institute, has also agreed to make six graduate fellowships in NDE available to the Center. Two of these will be available in '85-'86, a total of four in '86-'87, and a total of six in '87-'88. The number is planned to continue at that level after that time. These fellowships will be established as prestigious awards and will be filled through a nationwide competition. Recipients of the awards will matriculate through established disciplinary departments and will perform their graduate research in the Center under the auspices of their faculty advisors. Disciplinary backgrounds in various engineering fields as well as applied sciences will be considered appropriate and in keeping with industrial desires for people development in NDE. It has also been agreed that these fellowships will carry an annual stipend approximately 25% higher than the average graduate stipend in order to provide a motivation for excellence.

2. Graduate Student Support

In addition to the fellowships described above, it is expected that graduate student support in the Center will be provided through usual University channels. Current plans call for one starting in '85-'86 and increasing to four in '87-'88. These graduate students will also be enrolled in a disciplinary department and participate in the Center with their advisors on Center projects. It can be expected that this support will increase above the stated levels if the Center grows well.

D. Research Equipment

An extensive variety of research equipment is in place at Iowa State University and the Ames Laboratory, much of which is owned by various federal agencies (e.g., DOE, DOD). Permission has been obtained to use this equipment on appropriate Center projects on a non-interfering basis. Specific items of equipment that will be used in the research program are listed in the appropriate projects (cf. Technical Program Plan).

E. Curriculum Development

As the Center for NDE becomes established, it is expected that future directions for educational offerings will come via joint input from both partners in the Center. Funds made available from the Center for faculty research salaries will be matched with a commitment from the University to provide appropriate individuals to develop and to teach specific courses deemed necessary for the educational and technical missions of the Center. The Dean of the College of Engineering has approved two new faculty positions for this purpose at this time.

F. Facilities

Additional facilities at Iowa State University are needed to provide optimal housing for the Center for NDE. To alleviate this difficulty, Iowa State University has accepted the commitment to develop a suitable facility that is in keeping with the needs of the NSF University/Industry Cooperative Research Center's program. These needs include laboratory and office space for faculty and students as well as facilities for housing representatives of participating

industries during their stays at the Center (cf. Technical Program). As would be expected, a strong showing of industrial interest in, and cooperative support of, the Center will be influential in hastening this development. Current activity aimed at the selection of most desirable sites for this development is already underway. While awaiting permanent facilities, commitments have been made to consolidate the Center's work in the Metallurgy Building on the campus.

Iowa State University and the Ames Laboratory are well staffed and facilitated in the way of design, machine, and electronic shops. It is planned that the Center will make use of these facilities and staff through existent procedures.

Iowa High Technology Council

The Iowa High Technology Council has been formed to assist in the development of high technology activities in Iowa that will help to diversify the Iowa economy and to produce new jobs in Iowa. A Center for NDE readily falls into this category. To date, the Council has made \$160,000 available to the Center for research equipment. This money has been used to purchase computerized artificial intelligence equipment that will be used in the Center's research program. The Council makes awards to winning, competitive proposals in a continuing way, and has indicated that proposals from Centers command a high priority. It is fully expected that awards of the above kind will continue to be won by the Center in future years.

National Science Foundation

The National Science Foundation is committed to a five-year program of funding for the Center provided that industrial interest and cooperative support is also forthcoming. As noted earlier, the NSF support is expected to decline in the latter part of the five year period and to cease after five years. It is their expectation that this roll-off and cessation will be compensated by University and industrial support after this period if it is demonstrated that the Center truly serves industrial needs in the five-year period. It should be noted that NSF has offered an invitation to other federal agencies to join with them in their sponsorship of the Center.

III.D.3. Resources Needed - Industrial Participants

The only funding ingredient yet missing in the development of a Center for NDE at Iowa State University is a committed industrial participation. This participation is the key to success, for the entire purpose of the NSF cooperative program is to catalyze Centers that promote university-industrial cooperation and that are of use and value to industrial productivity in key areas of science and engineering. NDE amply satisfies these criteria. It is planned that this Prospectus will serve as the vehicle for bringing this component into being; the results of the Formation Meeting on Nov. 19-20, 1984, suggest that there is a sufficiently large number of interested industries to make it happen.

III. E. Technical Program Plan

The Technical Program Plan that was presented in the Draft Prospectus resulted from discussions and inputs from approximately seventy five (75) industrial representatives. That plan was reviewed at the Formation Meeting held on Nov. 19-20, 1984, in Des Moines. Comments obtained in that review and subsequent to that meeting have been incorporated into the present Technical Program Plan. Thus, the Technical Program Plan proposed in this Prospectus represents a refined program in which elements have been prioritized according to levels of industrial interest. As noted in the previous section on Management Plan, the IAB will play a key role in the evolution of this initial plan.

The Technical Program Plan consists of four elements. These are discussed below.

III.E.1. Research Program

The research program that has been developed and reviewed by industrial colleagues consists of seven projects. These projects, whose titles are given in Table I, are described in detail in Appendix A. This Appendix also contains a review of other NDE research in progress at Iowa State University and the Ames Laboratory. In addition, the projects contain references to specific items of research equipment that will be used in pursuit of the work. Brief resumes of investigators who will be involved with the various projects are collected in Appendix B.

Table I. Proposed NDE Research Projects

-
1. Advanced Signal Processing Techniques for Flaw Sizing and Characterization
 2. NDE System Design and Component Inspectability
 3. X-Ray and Magnetic NDE Technique Development
 4. NDE of Ceramics and Coatings
 5. NDE for Materials Properties
 6. NDE Technology for Advanced Composites
 7. System Integration, Test, and Evaluation
-

III.E.2. Cooperative Exchange Program

There is a strong interest among potential industrial sponsors in the development of an Exchange Program at the Center that will substantially contribute to a student's education and to the improvement of technology transfer. This effort will have two parts. One of these will be an internship in which a graduate student pursuing a degree program and research in the Center will go to an industrial site for a period of time (to be determined) as part of his/her program. Preferably, intern time would be taken within the student's program so that he/she has both pre- and post-experience in the Center. The second part of the Exchange will involve in-residence time in the Center for qualified Industrial Participants or their designee to work on project problems or on problems of their own choosing. The time available for this exchange will largely be matched to the Industrial Participants time requirements. In some cases, invitations will also be issued to selected Industrial Participants to serve in a Visiting Professor or Adjunct Professor role for the purpose of introducing specialty topics into curriculum offerings in cooperating University departments. These invitations will be issued by appropriate University officials.

III.E.3. Annual Research Conference

Over the past several years an annual research conference in NDE has been sponsored by the NDE programs at the Ames Laboratory and Iowa State University with the cooperation of federal agencies (DARPA, AF, NSSC, BES-DOE). This meeting has grown in size to approximately 300 persons, and perhaps represents the best meeting in the country (and possibly the world) in the presentation of advanced research results. Its focus is placed on the interface between basic research and early engineering development. The proceedings of the meeting are published in hard copy format by Plenum Publishers. The Center will be included as a sponsor of this meeting. Industrial Participants of the Center will be invited to send a representative to this meeting. He/she will receive a waiver of registration fees and a copy of the Proceedings at no cost. Members of the Industrial Participant company will also be invited to submit their own papers to the meeting. A juried paper selection process is used to maintain a high research quality of the program.

III.E.4. Information Dissemination Program

Industrial Participants will receive all preprints, reprints, and reports of research performed in the Center as a matter of course. There are several additional capabilities available at ISU for information dissemination that may be utilized by Industrial Participants through the Center to meet specific requirements. These include the development of short courses, video presentations, extensive library services, etc. Since these requirements are likely to be specific in nature, any Center funds expended in developing this capability will only be done with the express approval and guidance of the IAB. The Center management will, however, assist any Industrial Participant who has specific needs in this area to make the appropriate contacts and arrangements.

III.E.5. NDE Education at Iowa State University (In-Place at University)

There are two principal aspects involved in the academic education of graduate NDE engineers. These include academic preparation in curriculum work and the pursuit of research that will lead to a thesis of academic quality. As has been indicated, the Center will not be involved with the teaching function per se, but will be involved in the latter. The teaching function has been, and will continue to be, developed as part of the University's role. This section provides an overview of the educational opportunities currently in place at Iowa State University and guidelines that describe expected developments.

As is true elsewhere in the United States, Iowa State does not have a formal, structured curriculum or program in Nondestructive Evaluation Engineering. However, it is true that extensive research in NDE is being pursued by the faculty and graduate students at Iowa State University. To supplement and complement this research effort, Iowa State has introduced courses in NDE at both the undergraduate and graduate levels, and is in the process of developing others. Thus, Iowa State's approach is to graduate disciplinary engineers with a strong NDE option as described earlier. It is expected that masters degree engineers will form an important part of the graduating cadre.

An important course, because it first introduces the student to the concepts of NDE, is a senior-graduate level course which surveys the various NDE techniques. The course is taught jointly by the Departments of Engineering Science and Mechanics and Materials Science and Engineering. It has been taught now for five years, starting out with an enrollment of 14 students. In 1984-85 it had grown to 160 students that represent nine different departments in the College of Engineering. This growth curve is shown in Fig. 6. Since it is a survey course, it obviously cannot cover any one topic in depth. It does, however, introduce the student to the standard NDE techniques including ultrasonics, penetrants, eddy currents, magnetic particle measurements, neutron radiography, and acoustic emission.

A companion course at the same level is a hands-on laboratory course which gives the student actual experience with NDE testing equipment in applying some of the principles taught in the recitation course. The laboratory, because of equipment limitations, is limited to 12 students per section per term; five sections are currently being taught. Even with the extensive section structure, there are many more students than can be accommodated who would like to take the course; additional laboratory teaching equipment must be procured. Specific experiments include the use of dye penetrants, eddy currents, magnetic particles and ultrasonics.

A graduate level course called "Fundamentals of Ultrasonic and Electromagnetic Measurement Principles", has been introduced recently. The title is indicative of the material covered, but beyond these basic principles, the course shows how the principles apply in NDE. Currently, this is a one semester course, but consideration is being given to expanding this material to a year-long sequence.

An existing graduate level course in signal processing has been devoted primarily to these techniques as they apply to acoustics and noise control in architectural structures. This course is being restructured to include the application of signal processing techniques in NDE. Other graduate level courses are in the discussion and planning stages. What also should be noted is that there are in place, and have been for some time, courses which do not carry the

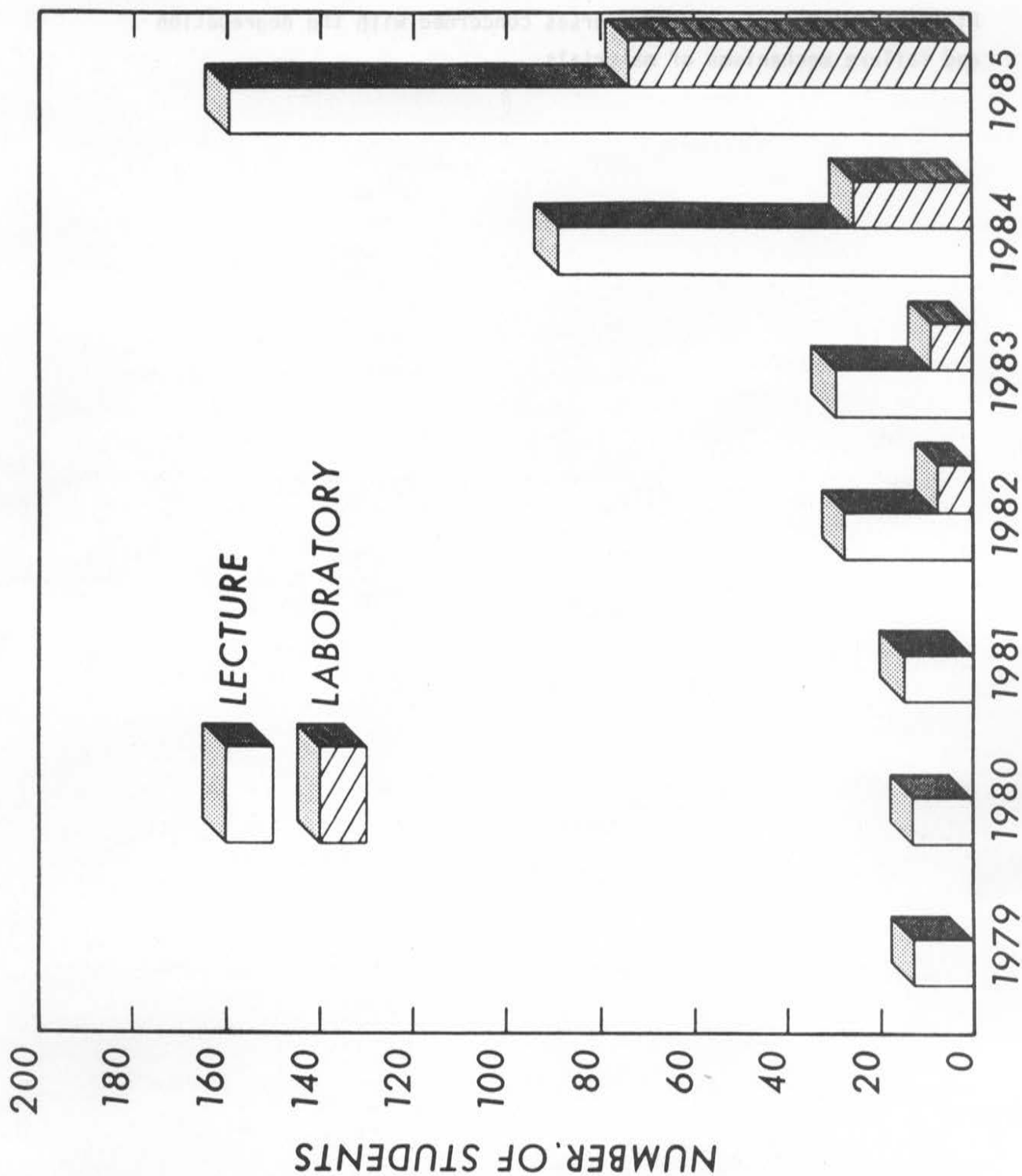


Figure 6. Growth of NDE Student Enrollment at ISU.

specific NDE identification, but which are essential components of an educational program with an emphasis in NDE. These include among others, Fracture Mechanics, Advanced Mechanics of Materials, Finite Element Analysis and courses concerned with the degradation and failure mechanisms of materials.



III. F. Fiscal and Staffing Plans

Table II shows a target fiscal plan for the first six years of the Center based upon commitments made and expected industrial participation. Goals for Center income are shown in the top half of the table while Center expenses are given in the bottom half. The Industry income has been calculated assuming \$35,000 each annually from each Industrial Participant with a maximum membership of thirty (30) Industrial Participants in '90-'91. Items of cost contained in Materials and Services include purchased services at the ISU or Ames Laboratory electronic and machine shops, graphics services, publication charges, telephone services, office supplies, computer time at the ISU or Ames Laboratory central computers, and travel funds for Center investigators. Details of equipment costs are listed by each project and task (cf. Appendix A). These items are needed to fulfill the specific work plans and represent a minimal addition to the extensive equipment base already in place that will be used in this program on a non-interfering basis. No adjustments have been made for inflationary increases over this period of time. As in all such long-range plans, the entries represent best judgements that can be made at this time. The Center's annual fiscal plan will be reviewed with the IAB for comments and recommendations before implementation.

Table III gives a Center staffing plan that is consistent with the fiscal plan. It shows the Center staff that would be supported by both the Center and the University in terms of a full-time equivalent count (FTE). The total number of persons working in the Center is thus the sum of both contributions, and shows a good mix of faculty, graduate students, and a limited number of full-time Center staff (technicians, programmers, etc.).

TABLE II
PROJECTED FISCAL PLAN (IN THOUSANDS)

	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91
# OF INDUSTRIAL PARTICIPANTS	15	20	22	25	28	30
<u>INCOME</u>						
National Science Foundation	75,000	75,000	75,000	50,000	25,000	0
Industry	525,000	700,000	770,000	875,000	980,000	1,050,000
State of Iowa						
EMRRI						
Senior Researchers	100,000	175,000	175,000	175,000	175,000	175,000
EMRRI Fellowships	28,000	56,000	84,000	84,000	84,000	84,000
College Support	24,000	36,000	48,000	48,000	48,000	48,000
Iowa High-Tech. Comm.	*	*	*	*	*	*
TOTAL INCOME	752,000	1,042,000	1,152,000	1,232,000	1,312,000	1,357,000
<u>EXPENSES</u>						
Wages & Salaries	461,554	674,628	747,846	805,780	867,103	901,343
Benefits	77,138	117,686	130,110	141,145	153,310	160,069
Materials, Services & Travel	71,308	99,186	108,545	118,076	128,087	135,588
Equipment	91,500	100,000	115,000	125,000	130,000	135,000
Contingency	25,000	25,000	25,000	25,000	25,000	25,000
Overhead	259,090	339,015	378,119	405,880	429,910	445,060
TOTAL EXPENSES	985,590	1,355,515	1,504,620	1,620,881	1,733,410	1,802,060
Overhead charges cost shared by ISU	(233,590)	(313,515)	(352,620)	(388,881)	(421,410)	(445,060)
NET EXPENSES	752,000	1,042,000	1,152,000	1,232,000	1,312,000	1,357,000

* Continued funding expected through individual proposals for equipment.

TABLE III
STAFFING PLAN
(FTE's)

Center Supported	'85-'86	'86-'87	'87-'88	'88-'89	'89-'90	'90-'91
Research Faculty	4.3	5.3	5.8	6.0	6.5	7.0
Graduate Students	9.0	11.0	12.0	15.0	16.0	18.0
Support Persons						
Technicians/Programmers	1.0	2.0	2.0	2.0	3.0	3.0
Secretarial	1.0	1.0	1.0	1.0	1.0	1.0
Program Staff	0.5	0.5	0.5	1.0	1.0	1.0
Total FTE's	15.8	19.8	21.3	25.0	27.5	30.0
University Supported						
Research Faculty (EMRRI)	1.0	2.0	2.0	2.0	2.0	2.0
Teaching Faculty (Depts.)	0.5	1.0	2.0	2.0	3.0	3.0
Graduate Fellowships						
EMRRI	2.0	4.0	6.0	6.0	6.0	6.0
Departments	2.0	2.0	4.0	4.0	4.0	4.0
Total FTE's	5.5	9.0	14.0	14.0	15.0	15.0

IV. SUMMARY AND BENEFITS

This Prospectus presents a plan for the establishment and operation of a Center for NDE at Iowa State University that will be developed under the joint sponsorship of Iowa State University, sponsoring industries, and the National Science Foundation University/Industry Cooperative Research Program. The entire plan has been reviewed with approximately 60 industrial representatives at the Formation Meeting in Des Moines, Iowa on Nov. 19-20, 1984; comments received both at and after that review have been incorporated, to the extent possible, into this Prospectus. Thus, it is believed that the plans presented herein are closely allied with a broad spectrum of industrial interests and focus upon topics of significant technological importance.

Because this Center plan has been developed to address deficiencies in NDE of a historical origin and is positioned to take account of current and future industrial needs, the Center for NDE will provide a way to realize substantial improvements in NDE technology and its industrial utilization as a key tool of quality control and productivity enhancement. Simultaneously, it provides a way to produce a significant advance in the development of industrially oriented engineers in a people-limited field.

Industrial Participants of the Center should realize several important benefits from their involvement in the Center. They are:

- Direct involvement in a highly leveraged, cooperative, industry-directed cooperative research program in NDE. The benefits of this research program are further leveraged by additional, federally-funded research programs in NDE already in place at Iowa State University and the Ames Laboratory.
- Early access to a new source of industrially-oriented NDE engineers.
- Opportunity to guide and to assist the development of ways to improve technology transfer in NDE.
- Opportunity to influence directions in NDE educational developments through problem input to the Center and through possible Visiting and Adjunct professorial arrangements.

V. NEXT STEPS

There are several steps that must yet be taken in a timely way in order to establish the Center for NDE at Iowa State University. The first of these is the receipt of a signed Letter of Intent from the prospective Industrial Participant of the Center. Although non-binding, signing of this letter signifies the intent and commitment of the company to become an Industrial Participant of the Center for NDE. It is strongly desired that Letters of Intent from the founding group be returned by May 15, 1985. Copies of this Prospectus together with copies of the Letters of Intent will then be forwarded to the National Science Foundation's University/Industry Cooperative Research Center's Program office (Dr. Alex Schwarzkopf). This step is necessary in order to procure the NSF component of funding. NSF will make this decision on or about July 1, 1985; assuming a positive action, this decision will constitute start-up of the Center. Following this step, individual contracts will be negotiated between Iowa State University and companies who signed Letters of Intent. The goal is to have all contract negotiations completed by September 15, 1985. Efforts will be made in the negotiations to tailor fee payment schedules to the convenience of the individual Industrial Participants consistent with University requirements. These steps and schedules are summarized below.

<u>Step</u>	<u>Deadline</u>
1. Receipt of Letters of Intent	May 15, 1985
2. Transmit Final Prospectus and Letters of Intent to NSF	June 1, 1985
3. NSF Funding Decision	July 1, 1985
4. Contracts Negotiated with Industrial Participants	September 15, 1985

An example of the substance of a Letter of Intent is included with this Prospectus.

EXAMPLE LETTER OF INTENT

1985

Dr. D. O. Thompson
225 Applied Sciences Center
Ames Laboratory
Iowa State University
Ames, IA 50011

Dear Dr. Thompson:

We are interested in the program described in the Prospectus for a Center for NDE, and intend to become an Industrial Participant of the Center. It is our understanding that our initial commitment is for a three (3) year term at an annual fee of \$35,000. Funding for the second and third years will be provided on an incremental basis; detailed payment schedules will be worked out at a later date in concluding contractual negotiations. If unforeseen events occur, we reserve the right to cancel with six (6) months written notification.

Consistent with the idea expressed in Section III.C of the Prospectus, page 24, we plan to name _____ as our Center representative and to be our voting member on the Industrial Advisory Board. We also understand that this assignment can be changed at later times. We look forward to working with you and hope for a fruitful interchange.

Very truly yours,

APPENDIX A:
RESEARCH PLAN

A.1. NDE RESEARCH BASE AT AMES LAB/IOWA STATE UNIVERSITY

The Industry/University Cooperative Research Center will be able to draw heavily on a strong research base at the Ames Laboratory and Iowa State University. Under the support of a variety of agencies, programs in basic research (BES/DOE, AFWAL/DOD, ONR/DOD, NSF, ERI/Iowa), applied research (Sandia/DOE, EPRI, AFWAL/DOD, NSSC/DOD, Hi-Tech Commission/Iowa), and technology transfer (SRL/AFWAL/DOD, Private Industry, Individual Consulting) are in progress. In this section, the scope of these programs, which represent a research base on which the Center's activities will be built, will be reviewed. The general objectives of three of the programs will first be discussed so that the interrelationships of these continuing programs to one another and to the Center can be more clearly understood. This will be followed by a review of specific research tasks. The research descriptions will be organized based on subject matter, irrespective of funding agency, for technical clarity.

MAJOR CONTINUING PROGRAMS:

Air Force Wright Aeronautical Laboratories. The Interdisciplinary Program for Quantitative Nondestructive Evaluation was jointly established in 1974 by the Defense Advanced Research Projects Agency (DARPA) and the Air Force Wright Aeronautical Laboratories (AFWAL), with the Rockwell International Science Center serving as the prime contractor. Since that time, a few key personnel and the program management responsibility have moved to the Ames Laboratory. In addition, after a certain level of maturity was established, DARPA has withdrawn to concentrate their resources on new initiatives, as is their standard practice; the program continues under Materials Laboratory, AFWAL, sponsorship. The Interdisciplinary Program for Quantitative Nondestructive Evaluation has as objectives a) the pursuit of advanced research in quantitative techniques for NDE, b) the generation of solutions for specific window problems, c) establishment of a focal point for NDE research, d) promotion of communication between the research community and the NDE user, and e) promotion of the scientific image of NDE. Consistent with the mission of AFWAL, the specific problems addressed are taken from the aircraft and related industries. The tasks represent a combination of basic and applied research.

Basic Energy Sciences, U.S. Department of Energy. The Office of Basic Energy Sciences, U.S. Department of Energy (BES/DOE) has supported three independent programs at the Ames Laboratory which have had continuing interests in NDE problems for a number of years. The Engineering Sciences Program has a broad interest in sensors. The NDE effort at Ames is concerned with signal processing tools and ultrasonic flaw characterization and sizing instrumentation with an emphasis on integration of existent results. The Mathematical Program has a generic interest in the applied analysis of wave propagation problems with emphasis of direct scattering calculations and inversion techniques which are robust in the presence of realistic constraints. Applications of the generic results to a number of fields, NDE, geoprospecting, etc., are considered. Here, second generation flaw characterization and sizing techniques are developed. The Metallurgy and Ceramics Programs is concerned with the materials science aspects of NDE. Techniques to measure failure related material properties are sought. Problems are emphasized whose solutions require a joint knowledge of measurement techniques and material failure mechanisms.

Iowa Hi-Tech Council. The Iowa Hi-Tech Council was established by the state in 1983 to encourage research in advanced technologies of economic benefit to industry, business, or agriculture. Grants are awarded with the objective of a) creating new products, b) creating new jobs, or c) improving agriculture. A grant to the Engineering Science and Mechanics Department for the purchase and set-up of an artificial intelligence work station for NDE application has already been awarded, and it is reasonable to expect that additional grants will be awarded in the future.

RESEARCH DESCRIPTIONS:

The specific technical tasks supported by these, and other, programs fall in six technical areas: field-flaw interactions, NDE-design interface, material property measurements, interface characterization, NDE of composites, and calibration and novel probes. A brief summary of these activities follows.

Field-Flaw Interactions. The majority of the studies of field-flaw interactions have been concerned with ultrasonic and eddy current problems. Among the forward scattering techniques which have been employed are ray, quasi-static, and weak scattering approximations. In addition, boundary element techniques have been used and programs for computing numerical scattering values using a variety of theoretical techniques developed elsewhere are available. These solutions are applied to NDE problems in two different ways. When coupled with descriptions of the temporal and spatial radiation characteristics of transducers, they are used to make absolute predictions of the waveforms that would be observed in specific NDE measurement configurations (AFWAL). These models can be used to evaluate the reliability of various techniques for flaw detection or the accuracy of different flaw sizing techniques. For example, in a study recently completed for EPRI, the superiority of the tip-diffraction over the dB drop technique for sizing intergranular stress corrosion cracks was demonstrated. The forward scattering solutions also serve as the starting point, or "kernel", for the solution of the inverse scattering problem. A first generation of such techniques, e.g., the inverse Born and long wavelength sizing approaches, were demonstrated under AFWAL support. A hardware system for automatically implementing these approaches is under development as part of the BES/DOE Engineering Sciences Program. More sophisticated, second generation inverse scattering algorithms are being investigated under the support of both the BES/DOE Mathematical Program and a three-year, multi-investigators grant from the Office of Naval Research (ONR).

Electromagnetic techniques have received less direct attention by on-site researchers. To date, two-dimensional finite element and boundary element models are available. In addition, through the technical management of research done at other laboratories (Stanford, SRI, SwRI, NBS-Boulder) by subcontractors on the AFWAL sponsored quantitative nondestructive evaluation program, Ames Laboratory/ISU personnel have knowledge of, and access to, a much broader set of results. Plans to substantially increase the on-site interest are discussed elsewhere in this Prospectus.

NDE-Design Interface. A recurring problem in NDE is that of the uninspectable structure. This could be avoided by the development of a set of engineering tools to be used at the design stage to predict component inspectability. Such tools would obviously draw heavily on the understanding of field-flaw interactions discussed above. At the present time, models have been developed for predicting the probability of flaw detection in aircraft engine component geometries (joint program with Rockwell International Science Center under AFWAL support). Scenarios have also been proposed for the marriage of such predictive tools with CAD models (AFWAL). Through an equipment grant (Iowa Hi-Tech Council), a Symbolics 3670 workstation has been purchased which is allowing artificial intelligence procedures to be applied to these and related problems.

Material Property Measurements. The nondestructive measurement of failure related material properties is becoming of increasing importance in both process control and service monitoring applications. Ultrasonic techniques are being developed to independently measure stress and texture in metal polycrystals (BES/DOE Metallurgy and Ceramics Program). These rely on the variation of the velocity of horizontally polarized shear waves in the plane of the surface of the component under investigation. They are thus a generalization of the more familiar shear wave birefringence techniques. Techniques for measuring porosity in cast aluminum (AFWAL) and iron compacts (BES/DOE Metallurgy and Ceramics Program) are under investigation. Because of the difference of the relative magnitudes of pore and grain boundary scattering in the two materials, different approaches are required. Whereas attenuation or ultrasonic backscattering techniques are appropriate to detect porosity in aluminum, velocity measurements must be used in steel to avoid competing effects due to grain boundary scattering. In a newly initiated project (BES/DOE Metallurgy and Ceramics Program) the underlying physical principles of several magnetic techniques (coercive force, Barkhausen, noise, etc.) for measuring material properties (stress, fatigue, hardness, etc.) are being studied. The philosophy is that the best application results will be obtained if simultaneous measurements of several magnetic properties are used as the basis for the property prediction.

Characterization of Interfaces. Imperfectly contacting interfaces are encountered in a number of structural systems including fatigue crack surfaces under compressive load, wearing surfaces, solid state bonds, and shrink-fit joints. The theory of ultrasonic interaction with such interfaces has recently been developed and applied to the problem of characterizing fatigue crack closure (BES/DOE Metallurgy and Ceramics Program). Similar ideas have been successfully applied to the problem of measuring the coupling stresses of Nitinol, shape memory couplers for joining tubes in submarines (Naval Sea Systems Command). Application of the models to the characterization of solid state bonds is presently being evaluated (Sandia-DOE).

NDE of Composites. Interest in the NDE of composites is rapidly growing at Iowa State University. Included among recent activities are the development of a student operated facility for fabrication and mechanical testing (Aerospace Engineering Department), measurements of ultrasonic scattering from internal composite structure and the detection and characterization of porosity in composites (AFWAL), and calculations of the ultrasonic scattering from flaws (Naval Sea Systems Command). The understanding of the scattering from internal structure (fibers, fiber bundles, ply interfaces, etc.) is believed to be essential before the information contained in the scattering from flaws (crack, pores, delaminations) can be fully recovered and interpreted. In addition to these ultrasonic measurements, the electrical conduction transverse to the composite plane has been shown to be a percolation effect which is dominated by interfacial effects. Resistance measurements thus appear to be sensitive to fiber volume fractions and contact conditions as influenced by stress and moisture.

Calibration and Novel Probes. As a part of the research activities, various calibration techniques and novel probes have been developed. Included are procedures for the absolute calibration of an ultrasonic system (AFWAL), dynamic photoelastic techniques for characterizing ultrasonic transducers (ONR), noncontact EMAT probes for ultrasonic generation and detection (BES/DOE Metallurgy and Ceramics Program), and laser techniques for generating and detecting ultrasonic waves (Engineering Science and Mechanics Department). Also in existence

are systems for photoacoustic spectroscopy, thermal wave imaging, NMR, Fourier transform I.R. spectroscopy (Ames Lab) and transient thermal field signatures (Engineering Science and Mechanics Department).

It is believed that the research base and the capabilities described above provide an excellent foundation for the development of the Industry/University Cooperative Research Center. They contribute very substantially to an already highly-leveraged Cooperative Research Center program. Results from the research base are available for the establishment of background and initial points for Center investigations and to the Industrial Participants. Additional capabilities provide an excellent opportunity for extended cooperative research coverage as the new positions offered by EMRRI and the University are filled.

A.2. RESEARCH PROGRAM

The research program proposed in this Appendix has been assembled following a two-phase selection process. First, problem inputs were obtained from approximately seventy-five (75) industrial groups. A "straw man" research program was assembled following digestion of the content of those inputs and was presented in the draft Prospectus discussed at the Formation Meeting on Nov. 19-20, 1984. Participants in that meeting then provided commentary, critique, and ranking of the possible projects. The current program has thus evolved by taking the critique and ranking obtained at and following the Formation Meeting into account. The result is an excellent program that has benefitted from many interactions and discussions and that addresses a broad spectrum of industrial interests. Moreover, it is well suited to faculty-student interdisciplinary research. The original listing of problem inputs obtained from industrial groups is given in Table A.2.1. and a listing of proposed project titles that has evolved from this process is repeated in Table A.2.2.

Table A.2.1. Industrial Problems

-
- Sizing and Detection Algorithms (UT, EC) (including probabilistic considerations)
 - Methods (Algorithms) for S/N Improvement (UT,EC)
 - Computer Aided NDE
 - Process Models (plastics, rubbers, etc.)
 - Flaw Detection and Characterization in Complex Geometries
 - Performance Standards for UT and EC Probes
 - Integrated Sensors for Large Structures
 - Models for NDE System Design (UT,EC)
 - Application of NDE Models to CAD/CAM for Improved Inspectability
 - Risk (Trade-Off) Analysis
 - Detection and Measurement of Material Properties (residual stress, fracture toughness, strength) (UT)
 - Characterization of Morphology and Defect Structures in Cast Materials (Al, grey iron) (UT)
 - Material Sorting Using EC Techniques (Al/Li alloys, others) as Function of Heat Treat

- Characterization of Interfacial Solid State Bonds
- Measurements in ferromagnetic Materials
- Dimensional Gauging at Elevated Temperatures
- AE in Composites (FRP,MM;UT)
- Forward Scattering Damage Assessment (FRP,MM;UT)
- NDE of Wire Precursors, Matrix (MM,UT)
- Detection and Characterization of Flaws (Porosity, Impact Damage, Microcracks, Fiber Breakage, Others)(FRP;UT,EC)
- Effects of Defects in Composites (FRP,MM)
- Defect Detection and Characterization in Ceramics of Complex Shapes (UT,CT)
- Defect Detection and Characterization in Ceramic Coated Materials(TW)
- Production Implementable Software
- Production Implementable Test Techniques
- Quantitative Radiography (CT, μ -focus, low contrast, real-time)
- Scanning Technology (Compatibility with signal processing, hi-speed, large structures)
- Robotic Development for UT Scanning

Abbreviations used in table:

UT - Ultrasonics
 EC - Eddy Current
 TW - Thermal Wave
 CT - Computed Tomography
 FRP - Fiber Reinforced Plastic
 MM - Metal Matrix

Table A.2.2. Proposed NDE Research Projects

-
1. Advanced Signal Processing Techniques for Flaw Sizing and Characterization
 2. NDE System Design and Component Inspectability
 3. X-Ray and Magnetic NDE Technique Development
 4. NDE of Ceramics and Coatings
 5. NDE for Materials Properties
 6. NDE Technology for Advanced Composites
 7. System Integration, Test, and Evaluation
-

Some comments are in order regarding the projects included in this Prospectus. They are:

1. The goal of all research pursued in the program is to produce end results that are industry-implementable. This does not mean that each research project will produce results that have a stand-alone, industrially-implementable outcome; it does mean, however, that the results of all projects are needed to achieve the outcome and will be incorporated in appropriate ways. Thus, the projects contained in the plan extend from basic research through reduction to practice. For example, the basics of ultrasonics are further advanced than are those of eddy currents; therefore, the initial ultrasonic work is more engineering oriented. It can be expected that all subjects addressed will move in this mode as the program evolves. The end point of research in this program is taken to be the development of a working instrumental prototype, a software package, or a set of techniques that can then be finally engineered by the Industrial Participants for specific industrial application. It is expected that close, cooperative interactions will be initiated and maintained between Center personnel and the Industrial Participants during the several stages of development in order to assure this result.

2. A research program plan has been developed to meet an assumed budget of \$765K from sponsoring industry, NSF, and other organizations that is augmented by University contributions (cf. p. 43). It includes two tasks in x-radiography that were not included in the draft Prospectus but which were deemed important by industrial colleagues at the Formation Meeting. Correspondingly, a few very good tasks included in the draft Prospectus but which did not fall into a top priority industrial ranking have been eliminated to be within the budget target. If the actual budget should exceed the target amount, these tasks will be reviewed with the founding Industrial Advisory Board for possible later start-up. If the target budget is not reached, tasks will be dropped with the advice of the founding IAB.

3. The projects have been reordered from the format used in the draft Prospectus to better reveal the nature of the program plan. Projects 1,2,3, and 4 deal with NDE technique development. Techniques included are ultrasonics, eddy currents, x-ray, magnetics,

and thermal wave imaging. These five topics represent a very significant coverage of major NDE techniques; this coverage will be further extended with the addition of new people committed by the University and with an increased Center budget. Projects 5 and 6 show a materials property focus in which techniques of choice are used to gain desired property information. Techniques of choice include eddy currents, EMAT ultrasonics, conventional ultrasonics, and exploratory work with NMR. Project 4 could be placed in either or both categories; it is aimed at the development of thermal wave techniques for both characterization and flaw detection measurements in ceramic coatings and materials. Project 7 represents an initial start-up of a reduction to practice phase. Two topics are included in this project both of which have undergone significant earlier research and development in both the Air Force and BES programs. The topics include the development of an electromagnetic acoustic transducer (EMAT) prototype and software for field determination of a material's texture and an integrating, testing, and packaging of ultrasonic scattering results aimed at the development of ultrasonic standards. Texture has especial significance in drawing and forming operations, in determining the "stiff" direction of a rolled metal product, and may be useful in other material microstructural and residual stress determinations. This project provides a particularly clear example of the high leverage inherent in this cooperative research program.

4. Several other items of information are included with each project description. They include a listing of Investigators, equipment that is available for use on the project, and a specific budget (first year) by Project. Items of equipment that are yet needed are also listed on the budget page. A Center administrative budget page is also included. Please note two items on this page: 1) the salaries of the Director and Deputy Directors will be paid by the University for the first year, and 2) the salary for a computer programmer is listed in this category even though his services will be rendered in the various technical areas. (The total budgetary and staffing plans are given in the Prospectus, Section III.F and include the sum of all specific project budgets as well as other needed items.) Students who will be budgeted from Center funds are included by Project, but are not as yet named.

5. The proposed research program addresses a large majority of the problems listed in Table A.2.1. either directly or indirectly. For example, there is overlap between problems in some cases in which the solution of one bears strongly on the solution of another. In other cases, the problems listed are the final desired outcome of the effort; since some of these must be addressed on a more basic level, the described work may not show a 1-to-1 correspondence with the desired result. Some topics in Table A.2.1. have not been addressed at this time. In several of these cases, the topics of interest are being pursued in other programs described in A.1. under federal agency funding at Iowa State University, the Ames Laboratory, or at some other organization. Results of these federally funded programs are available to Industrial Participants; assistance in making these results available will be provided by the Center as industry desires. In a few other cases, the topics were not of sufficiently broad interest to potential Industrial Participants to warrant inclusion at this time in a cooperative program.

6. The proposed research program is an open-ended program and is always open to review and evaluation by the Industrial Advisory Board. Thus, the proposed program should be viewed as a starting point from which evolution will take place. It is important in the evolutionary process, however, to retain a stability that is necessary to produce both students and good research.

PROJECT 1. ADVANCED SIGNAL PROCESSING TECHNIQUES FOR FLAW
SIZING AND CHARACTERIZATION

OVERVIEW:

Over the past ten years, considerable improvements have been made in the capability of NDE measurements. Those improvements have allowed better flaw detection in poor signal-to-noise environments and better flaw sizing once they are detected. The development and application of models of the inspection process have been the key ingredients that have fueled this progress. Many of these developments are described in the published proceedings of the 1981-83 Review of Progress in Quantitative NDE meetings (1). Both scattering studies of the energy-flaw interactions and wave propagation studies to relate the fundamental scattering parameters to the actual signals observed at the probe terminals (either U.T. or E.C.) have been included.

The energy-flaw interaction studies include forward elastic and electromagnetic scattering problems, whereby the response to a known flaw are predicted, and inverse scattering problems, in which one seeks to identify flaw parameters from observed fields. Whereas deterministic solutions to the forward problem are possible (though perhaps quite difficult), probabilistic solutions are generally required in the inverse problems because of incompleteness or errors in the experimentally observable quantities. The tasks in this project will be primarily concerned with the development of improved signal processing for the classification and sizing of flaws.

The flaw parameters must ultimately be related directly to the signals observed at the probe terminals. The coupling of the flaw-energy interaction models to the laboratory observables has been based on wave propagation studies including the work of Thompson and Gray (2) in ultrasonics and Auld (3) and Lord (4) in eddy current testing. Further development of such comprehensive measurement models will be included in the efforts in Project 2, and those results will be incorporated in the tasks of Project 1 as appropriate. The distinction is as follows. Project 2 is primarily concerned with the development of accurate models of the entire inspection process and their use as engineering design tools. Project 1 is concerned with flaw sizing and characterization technique developments. The models serve as a computational test bed for evaluating techniques, but the primary research will be concerned with ways of extracting the necessary information.

In the initial years, the project will have two tasks, one concerned with ultrasonic problems and the second with electromagnetic problems. In the former case, a considerable body of knowledge is already available as a result of numerous studies of the inverse scattering problem conducted over the last decade. More detailed work is required in this area, and tasks will probably be initiated to that end in future years. However, at the present time, it is believed that it is timely to integrate the computer into the existing body of knowledge using both artificial intelligence concepts and high resolution graphics capabilities. This type of exploitation of computational resources will be referred to here as "computer-aided NDE" or "CANDE" for short, and is the subject of Task 1.1.

In the area of electromagnetics, the body of fundamental knowledge is much less complete. Task 1.2 will initiate in its first year with basic studies designed to elucidate fundamental electromagnetic principles whose ultrasonic analogs are already known. Efforts in the subsequent years will be directed towards more practical questions whose solutions can be based on this knowledge.

REFERENCES:

1. Review of Progress in Quantitative NDE, Vols. 1-3, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1982-1984).
2. R. B. Thompson and T. A. Gray, "A model relating ultrasonic scattering measurements through liquid-solid interfaces to unbounded medium scattering amplitudes", J. Acoust. Soc. Am., 74, 1279-1290 (1983).
3. B. A. Auld, F. Munnemann, and D. K. Winslow, "Eddy current probe response to open and closed surface flaws", J. NDE, 2, 1-21 (1981).
4. S. S. Udpa and W. Lord, "A Fourier descriptor classification scheme for differential probe signals", Materials Evaluation, 42(9), 1136-1141 (1984).

TASK 1.1. COMPUTER-AIDED NDE

OBJECTIVE:

To apply artificial intelligence (AI) and computer-aided NDE (CANDE) concepts to the integration of flaw detection, classification, and sizing methodologies.

SCOPE:

This task will combine ultrasonic signal processing methods, flaw scattering models, and flaw characterization techniques into an integrated flaw evaluation software package that uses symbolic processing and high resolution color graphics extensively. This package will provide a single, highly effective software environment for the development of improved flaw detection, classification, and sizing capabilities.

BACKGROUND:

In order to evaluate the significance of a defect in a part or structure, techniques from a diverse set of fields such as signal processing, materials science, scattering and probabilistic theories, etc. are normally required. The synthesis in software of these various knowledge bases poses a very difficult task via traditional programming approaches. By combining high resolution computer graphics and modern AI concepts of symbolic processing, however, flaws and flaw scattering signatures can be treated as abstract objects with properties that can be manipulated in a variety of quite different contexts.

Through the support of the Iowa High Technology Council, the Center for NDE at Iowa State University has recently acquired significant hardware and software facilities that will allow the pursuit of such NDE-related AI and CANDE applications. These facilities consist of a Symbolics 3670 workstation which combines both the LISP and FORTRAN languages with high resolution black-and-white and color graphics hardware/software and laser-generated hard copy output. Significant symbolic algebra capabilities also exist on this system in the form of the expert system MACSYMA. This Symbolics workstation will be networked to a Micro Vax-I system running the Micro-VMS

operating system and having device-independent graphics capability through Precision-Visuals DI-3000 graphics software. This microVax will serve as both a multiuser FORTRAN/GRAPHICS development workstation and as a means of providing a communication/data-transfer path between the Center's NDE experimental facilities and the symbol processing capabilities of the Symbolics workstation.

Under the sponsorship of the Iowa High Technology Council, we are currently applying AI concepts to the task of integrating knowledge bases from the areas of signal processing, pattern recognition, and flaw scattering theory to produce a new type of flaw classification software package that is applicable to ultrasonic testing. In particular, we are combining the measurement model of Thompson and Gray (1) with low frequency extrapolation techniques (2) and Fourier-Mellin transforms (3) to produce scale and translation invariant scattering signatures that can be correlated with known scattering patterns obtained from such methods as the Born and Kirchhoff approximations (4,5). The results of these correlations are then being used to classify an unknown flaw into a crack, void, inclusion, etc. category.

APPROACH:

FIRST YEAR. Such a classification capability, taken together with existing detection and sizing algorithms, forms a substantial portion of the ingredients needed in a complete flaw characterization procedure (Fig. 1). Here, we propose to use AI and CANDE concepts to combine all three of the ingredients into a single, integrated software package that uses symbolic processing and graphics capabilities extensively. In particular, we will develop a flaw representation language on the Symbolics 3670 system which will borrow many of the concepts that have been effectively used in the speech recognition field (6) to manipulate flaws and flaw signals. This flaw representation language will be coupled to an interactive user interface and to high resolution black-and-white and color display windows to produce a first generation CANDE facility for conducting ultrasonic evaluation studies.

During the first year we propose to integrate the signal processing and modeling methods necessary for performing classification and

sizing on flaws of a crack-like nature. This will allow us to develop the logical framework of our approach with an explicit important special class of flaws so that testing can be accomplished on both synthetic and experimental ultrasonic data and so that necessary iterative improvements in the software capabilities can be accomplished as early as possible. The classification methods will be drawn from the work described above which is currently being funded by the Iowa High Technology Council while the sizing methods will be initially "best fit" equivalent crack estimates using the Kirchhoff approximation (5) and regression analyses similar to those currently available for volumetric flaws (Fig. 1).

SECOND AND THIRD YEARS. During the second year of this task we will similarly integrate volumetric flaw sizing algorithms into the AI/CANDE environment and begin the necessary adaption of detection algorithms to this environment also. Again, significant testing of the package on realistic data will be an important part of this phase of the project. The third year will involve incorporating the selected detection methods, such as probabilistic approaches, into the flaw evaluation package and in examining the adoption of this fully developed concept to other testing methods such as eddy currents and radiography.

OUTPUTS:

1. A flaw characterization software package that can demonstrate the value of combining detection, classification and sizing algorithms into a highly integrated symbolic processing, CANDE environment.
2. Development of a methodology that can be incorporated into design and production-implementable software packages.
3. Development of a methodology that can be used for effectively combining evaluation procedures of different testing methods such as eddy currents, ultrasonics, and radiography, into a single, unified software environment.

INVESTIGATORS:

L. W. Schmerr
D. O. Thompson
2 Students

AVAILABLE EQUIPMENT:

Symbolics 3670 Workstation
 Micro-Vax-I System
 Multiviewing Transducer System

EQUIPMENT NEEDED (FIRST YEAR):

None

REFERENCES:

1. R. B. Thompson and T. A. Gray, "A model relating ultrasonic scattering measurements through liquid-solid interfaces to unbounded medium scattering amplitudes", J. Acoust. Soc. Am., 74, 1279-1290 (1983).
2. F. Cohen-Tenoudji, Y. Pralus, A. Lambert, G. Quentin and B. R. Tittmann, "Polynomial extrapolation towards low frequencies of the spectrum of gated ultrasonic echoes for deconvolution: Application to defects in solids", Review of Progress in Quantitative NDE 3A, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1984), pp. 359-372.
3. P. E. Zwicke and I. Kiss, Jr., "A new implementation of the Mellin transform and its application to radar classification of ships", IEEE Trans on Pattern Analysis & Machine Intelligence, PAMI-5, 191-199 (1983).
4. J. H. Rose and J. L. Opsal, "The inverse Born approximation: Exact determination of shape of convex voids", Review of Progress in Quantitative NDE 2B, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1983), pp. 949-959.
5. L. W. Schmerr and A. Sedov, "The time-domain elastodynamic Kirchhoff approximation for cracks. The direct and inverse problems", submitted to Wave Motion (1984).
6. G. E. Kopec, "The integrated signal processing system ISP", IEEE Trans. ASSP, ASSP-32, 842-851 (1984).

DECISION TREE FOR FLAW CHARACTERIZATION

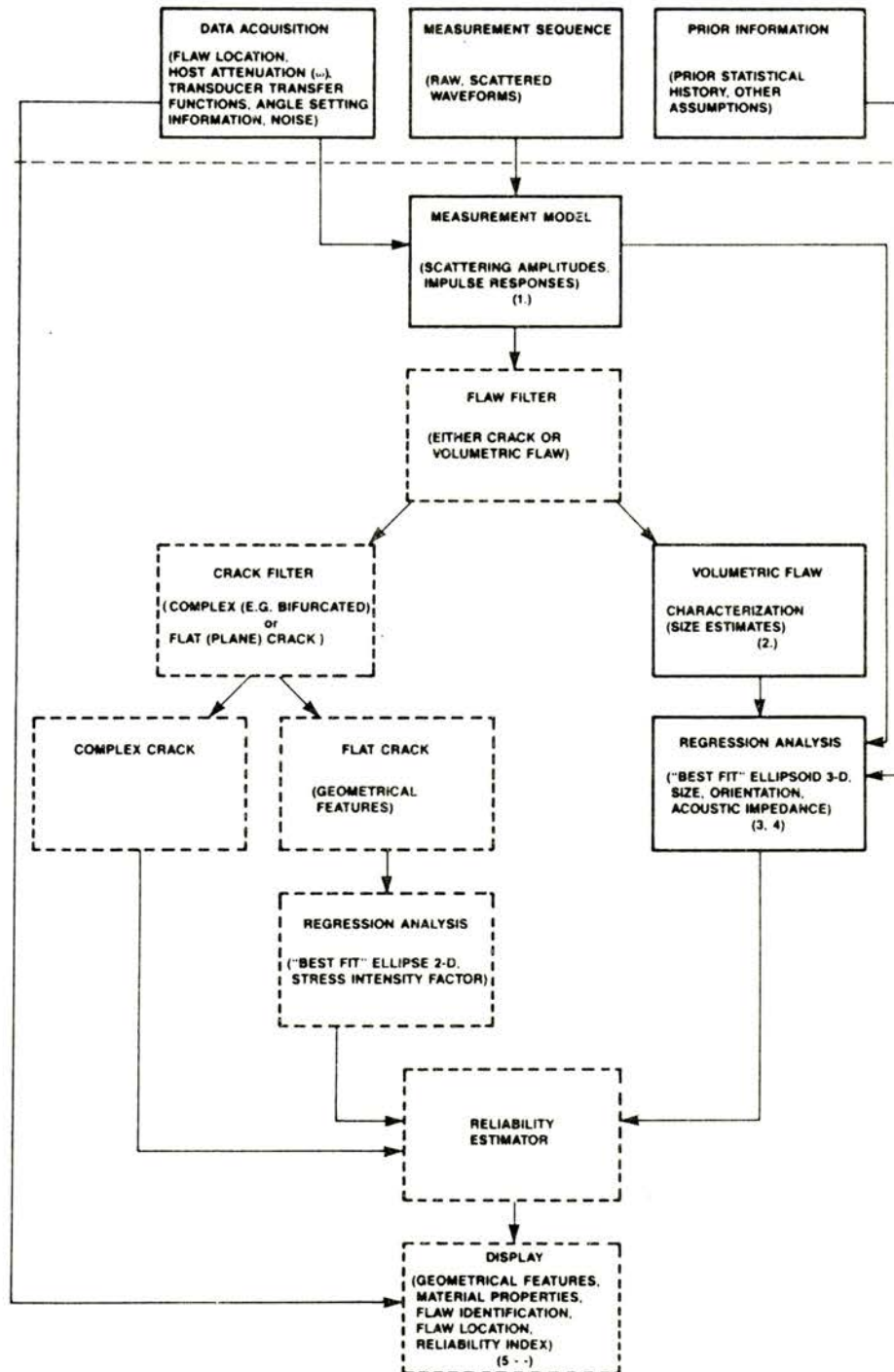


Figure 1.

BUDGET PLAN (FIRST YEAR)

PROJECT 1. ADVANCED SIGNAL PROCESSING TECHNIQUES FOR FLAW
SIZING AND CHARACTERIZATION

TASK 1.1. COMPUTER-AIDED NDE

INVESTIGATORS:

L. Schmerr	25.0%
D. Thompson	12.5%
2 Students*	

Wages and Salaries	\$ 34,957
Benefits	5,739
Materials and Services	5,000
Travel	2,000
Computer	1,000
Equipment	0
Indirect Costs**	<u>0</u>
Total Expenses	\$ 48,696

*Assumes one graduate assistant salary paid by EMRRI.

**Cost shared by ISU.

TASK 1.2. ELECTROMAGNETIC FLAW SIZING

OBJECTIVE:

To develop advanced electromagnetic techniques for sizing flaws.

SCOPE:

This project will be concerned with the fundamental principles of electromagnetic flaw sizing techniques. The techniques of inverse scattering theory, which have recently been applied with success to the ultrasonic scattering problem, will now be applied to electromagnetics, with primary emphasis placed on the special case of eddy current inspection. This analytical effort will be strongly coupled to the measurements and development of finite element codes, which will take place as a part of Task 2.2. Since both Task 1.2 and Task 2.2 represent new directions at Ames, the first year's efforts in each will be devoted towards establishing foundations. In Task 1.2, the general character of exact inverse solutions to the three-dimensional electromagnetic field equations will be examined. In subsequent years, specific applications to flaw characterization and sizing in metals will be developed. During those studies, the computational capabilities developed during the first year's effort in Task 2.2 will serve as an important source of synthetic data for testing the new flaw characterization methods.

BACKGROUND:

Eddy currents occur whenever a time dependent magnetic field interacts with a conducting medium. The eddy currents produced depend upon the frequency and amplitude of the magnetic field, the conductivity of the medium, and the permeability of the medium if it is ferromagnetic. The depth of penetration of the eddy current decreases with conductivity, frequency, and permeability.

The use of eddy currents as a non-destructive testing technique has long been realized (1,2). Greatest applications are in the non-ferrous metals. In the case of ferrous materials, the interpretation is complicated by the necessity of having a mathematical relationship between B and H in order to interpret the results (3).

Eddy current techniques are best suited to the detection of cracks and defects such as non-conducting voids. This use of eddy currents as a qualitative tool is well established and commercial eddy current crack detectors have been available for some years

now. However, there is enormous room for improvement in its use as a quantitative method. Such information as crack length, depth and orientation are of crucial interest when deciding, for instance, whether a component should be removed from service. Current research is aimed at the development of new detectors with improved sensitivity and in the development of flaw sizing algorithms. The latter are in a much more elementary state than in the ultrasonic case. Field practice makes use of the variation in signal strength as the probe is moved. Surface length resolution is limited by the size of the probe, and little depth information is obtained. Research results have suggested that the frequency dependence of the signal phase would be valuable in determining the latter quantity (4). However, the options in signal demodulation are just beginning to be explored (5).

APPROACH:

First Year's Effort. During the first year the underlying formalism of inverse scattering theory for the electromagnetic wave equation will be examined. The majority of the period will be concerned with formulating the exact inverse scattering equations. That effort will rely heavily on experience gained in recently developed solutions for Schrödinger's equation $((\Delta - k^2 - v(\vec{x}))\psi_k(x) = 0)$ and the plasma wave equation $((\Delta - \partial_t^2 - v(\vec{x}))\psi_k(x) = 0)$ (6) and in in-progress solutions to the acoustic wave equation. During the last quarter, attention will be focussed on the particular case of a metallic medium.

Second and Third Year's Effort. During the second and third year, the general formalism will be utilized in the development of practical algorithms for sizing flaws in metals. That effort will have been initiated by the studies of conducting media at the end of the first year and will be concerned with the fundamental limits placed on flaw characterization by the resulting diffusive nature of the wave equation. Through a study of time domain inverse scattering, the limits on sensitivity and resolution will be explored.

The results of the general theory will be examined in light of recent results in both acoustics and electromagnetics which employ the results of the Born approximation as discussed below. It is felt that this practical model-based approach, combined with the

insight of an exact analysis of the electromagnetic inverse problem will lead to substantial progress on the flaw characterization problem.

Recent studies in the AF QNDE program and elsewhere have shown that eddy current crack sizing methods depend sensitively on the frequency variation of the signal, particularly its phase. These results have been emphasized by Auld et al. (4) using a frequency domain picture to model eddy current interactions with a half-elliptical surface crack. In his analysis, Auld used approximations analogous to those employed in the frequency dependent inverse Born approximation for ultrasonic waves, which is most easily understood in the time domain (7). Consequently, we propose to re-express the model based sizing studies described above in the time domain. If this approach appears fruitful, we will then develop a model independent flaw sizing method based on the weak scattering formulation of the electromagnetic integral equation. Besides providing basic insights, the results will be directly applicable to the interpretation of pulsed eddy current methods.

OUTPUT:

1. Formal inverse scattering solutions for the electromagnetic wave equation.
2. Understanding of the limits placed on sizing capability by the diffusive nature of the wave equation in metals.
3. Time domain (pulsed e.c.) algorithms for flaw sizing.

INVESTIGATORS:

J. H. Rose

Post-Doctoral Student or Graduate Student

AVAILABLE EQUIPMENT:

Vax Computers

EQUIPMENT NEEDED (FIRST YEAR):

None

REFERENCES:

1. H. L. Libby, Introduction to Electromagnetic Nondestructive Test Methods, (Wiley-Interscience, New York), 365 pages, 1971.
2. Fordham, P., "Non-destructive testing techniques", Business Publications, London (1968).
3. Stoll, R. L., "The analysis of eddy currents", Oxford, CO (1974).

4. F. Muennemann, S. Ayter and B. A. Auld, in, Review of Progress in Quantitative Nondestructive Evaluation 3A, 621 (1984).
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6. J. H. Rose, M. Cheney and B. DeFacio, J. Math. Phys. 25, 2995 (1984).
7. J. H. Rose and J. M. Richardson, J. Nondestructive Evaluation 3, 45 (1982).

BUDGET PLAN (FIRST YEAR)

PROJECT 1. ADVANCED SIGNAL PROCESSING TECHNIQUES FOR FLAW
SIZING AND CHARACTERIZATION

TASK 1.2. ELECTROMAGNETIC FLAW SIZING

INVESTIGATORS:

J. Rose	25%
1 Student	

Wages and Salaries	\$ 21,780
Benefits	2,595
Materials and Services	2,000
Travel	2,000
Computer	1,000
Equipment	0
Indirect Costs*	<u>0</u>
Total Expenses	\$ 29,375

*Cost shared by ISU.

PROJECT 2. NDE SYSTEM DESIGN AND COMPONENT INSPECTABILITY

OVERVIEW:

This project is designed to integrate various elements of NDE modeling and place them into a format which can be used for two new engineering functions. The first goal is to develop a capability of modeling the performance of an NDE measurement system. This would allow new NDE systems to be designed analytically, with predictable performances, rather than by cut and try techniques. The second goal is to combine this capability with computer-aided design (CAD) software. Such a marriage of technologies would allow inspectability to be evaluated as part of the design process. The result would be a procedure for avoiding unacceptably low probabilities of detection.

In order to reach these objectives, four tasks are included. One must first extend and verify presently existing models of ultrasonic and eddy current measurements for realistic part and flaw geometries. The models must then be integrated with statistical methodologies to produce a set of software capable of predicting probabilities of detection (POD's) and sizing accuracy. This will be the goal of the first year of the program, which will rely heavily on initial results obtained under Air Force sponsorship. At this point, one is in the position of being able to predict the performance of a proposed NDE system. In the second year, the utility of this approach would be demonstrated by using it to assess trade-offs in part design versus inspectability for a specific demonstration example. In the third year, the new capability would be explicitly interfaced with a CAD system.

In distinction with the other projects in this prospectus, the task descriptions which follow have a sequential, as well as simultaneous, time frame. Tasks 2.1 and 2.2 will be conducted during the first and second years of the project. Their outputs will be combined into tasks 2.3 and 2.4 which will be carried out during the second and third years, respectively. Because of this sequential nature, no investigators nor budget requests are provided for Tasks 2.3 and 2.4 at this time.

TASK 2.1. DEVELOPMENT OF A MODEL-BASED ULTRASONIC NDE SYSTEM
DESIGN TECHNOLOGY FOR COMPLEX GEOMETRIES

OBJECTIVES:

The objective of this task will be to develop a model-based software package which will have the capability of quantitative assessment of the applicability of ultrasonic NDE systems to given inspection tasks. This package will incorporate analytical and numerical models which predict ultrasonic propagation characteristics associated with complex part geometries, which compute the strength of ultrasonic elastic wave scattering from a variety of defects, and which simulate the effects of typical sources of noise. These models will be integrated into a software framework which will predict such NDE system performance characteristics as probability of detection (POD) and sizing accuracy.

SCOPE:

This task will address a major problem facing the implementation of ultrasonic NDE techniques in practical applications, namely, the qualification of such systems for given inspection tasks. Such qualification is typically performed through the use of limited experimental trials on calibration samples. This approach is generally quite expensive due to the cost of machining appropriate test samples. In addition, it is difficult to guarantee the completeness of such a regimen regarding defect types, part geometries, etc. An alternative approach to the qualification of an NDE system is to utilize model-based software which incorporates the key features of the inspection requirements to predict the system performance. This approach allows both interpolation between sparse experimental data and extrapolation of such results to cases not covered by experiments. Development of a software package to perform this evaluation function is the goal of this task. Included will be a strong experimental component to assess the validity of the models and to guide the development of new modeling approaches if warranted. This package will provide an operational tool which will enable the NDE system designer to assure the best inspection capabilities through specifications of scan parameters, choice of appropriate ultrasonic probes, determination of suitable

system calibration and threshold levels, and selection of signal processing approaches which yield the best defect classification characteristics.

BACKGROUND:

A considerable knowledge base concerning the phenomena associated with ultrasonic beam propagation and elastic wave scattering has been developed in the Defense Advanced Research Projects Agency/Air Force (DARPA/AF) program in Quantitative NDE (1). An important application of this knowledge has been the development of a measurement model (2) which relates the measured ultrasonic signal from a defect to the far field scattering amplitude from that defect; this is an absolute quantity related to the geometrical and material properties of the flaw. The model was originally conceived as a signal processing tool to correct measured ultrasonic data for the effects of beam diffraction upon flaw sizing using the inverse Born approximation (4). The model found subsequent application in the prediction of the signals which would be obtained in practical ultrasonic measurements from various defects, such as voids and cracks, below planar or curved part surfaces (2,3). Further evolution of this approach has led to the ability to predict signal-to-noise ratios for cracks in the presence of noise due to porosity and electronic system characteristics (5) and to simulate the response of scanned ultrasonic systems (6) in simple part geometries. Current work is being performed to extend the models to complex geometries and to allow quantitative assessment of the effects of aberration of ultrasonic beams which occur due to oblique incidence upon curvature of part surfaces.

APPROACH:

First Year's Effort. This task will begin with a combined experimental and computational investigation of the limits of applicability of present modeling approaches used in techniques for detection and characterization of defects when applied to inspection in complex geometries. These models incorporate paraxial theories for propagation of ultrasonic beams generated by piston or Gaussian probes through interfaces of planar, cylindrical or bi-cylindrical shape.

To extend the models to cases where aberrations play a significant role, a series of approximations for treating wave propagation through complex shaped interfaces will be examined. The initial work will treat cylindrical surfaces so that the problem will be reduced to two dimensions. A general ray tracing program will first be prepared, followed by the development of models to assign amplitudes to the ultrasonic fields. Several candidate approaches to this are envisioned including asymptotic expansions, complex ray theory based upon the complex source point method, and expansions of the fields in terms of orthogonal functions, such as Gaussian-Hermite functions. Predictions of the models will be compared to experiment to assess accuracy. Subsequent efforts will then generalize the results to three-dimensional problems.

Following the development of beam propagation models, the results will be incorporated into a measurement model for predicting the absolute strength of signals as measured in practical inspection of complex shaped parts. This measurement model will be subjected to experimental verification on samples containing known defects and having complex shapes. Particular attention will be placed upon the ability to predict the detected amplitude in a scanning mode which is essential to the development of NDE systems.

The next thrust in this task will be to apply models of UT probe field interactions in complex geometries to techniques to improve the reliability of a NDE system. Two major abilities are essential for reliable NDE inspection - high detection sensitivity and accurate characterization capability. For a given inspection hardware configuration, both of these abilities can be improved through the use of modeling.

This step will thus be the integration of the previous work into a model-based software package for predicting and classifying NDE system performance based upon detection sensitivity and characterization accuracy as discussed in the preceding paragraphs. For an assumed part geometry, defect type, and candidate NDE system, this package will compute a figure of merit for that configuration based upon predictions of POD and defect sizing capability. In addition, this

package will allow variation of system components such as probe characteristics, scan parameters, etc. which are consistent with the candidate NDE system in order to determine means for improving performance.

OUTPUT:

1. Models of ultrasonic beam effects associated with passage through complex shape parts.
2. Integrated model-based software to assess NDE capability (POD and sizing accuracy) of an ultrasonic inspection system.

INVESTIGATORS:

T. A. Gray
R. B. Thompson
Student

AVAILABLE EQUIPMENT:

UT Data Acquisition Equipment

Tektronix 4052A Desk Top Computer

Tektronix 7912AD Programmable Digitizer with

7416P Programmable Amplifier

7B92A Dual Time Base

Panametrics 5052PR Spike Pulser/Receiver

Testech Immersion Tank with Two Manual 5 DOF Manipulators

Computational Facilities

Digital Equipment Micro VAX I Computer

Digital Equipment LSI-11/23 Computer

Symbolics 3670 Artificial Intelligence Workstation

Access to DEC VAX-11/780 Computer

EQUIPMENT NEEDED (FIRST YEAR):

None

REFERENCES:

1. Review of Progress in Quantitative Nondestructive Evaluation, Vol. 1-4, D. O. Thompson and D. E. Chimenti, Eds., (1982-1984).
2. R. B. Thompson and T. A. Gray - J. Acoust. Soc. Am. 74, p. 1279 (1983).
3. R. B. Thompson and T. A. Gray, in, Review of Progress in Quantitative NDE 3A, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1984), p. 373.
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5. T. A. Gray and R. B. Thompson, in, Review of Progress in Quantitative NDE 3A, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1984), p. 47.
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BUDGET PLAN (FIRST YEAR)

PROJECT 2. NDE SYSTEM DESIGN AND COMPONENT INSPECTABILITY

TASK 2.1. DEVELOPMENT OF A MODEL-BASED ULTRASONIC NDE SYSTEM
DESIGN TECHNOLOGY FOR COMPLEX GEOMETRIES

INVESTIGATORS:

T. Gray	50.0%
R. B. Thompson	12.5%
1 Student	

Wages and Salaries	\$ 38,991
Benefits	6,898
Materials and Services	5,500
Travel	2,000
Computer	1,000
Equipment	0
Indirect Costs*	<u>0</u>
Total Expenses	\$ 54,389

*Cost shared by ISU.

TASK 2.2. DEVELOPMENT OF EDDY CURRENT MODELS FOR FLAW DETECTION AND CHARACTERIZATION

OBJECTIVES:

The objective of this task is to develop a model-based software package which will have the capability of quantitative assessment of the applicability of an eddy current NDE system to a given inspection problem. The models will utilize both numerical (e.g., finite element) and analytical techniques to relate impedance changes as seen at the probe terminals to flaw geometry. They will be in a suitable format for additional use in probe design for specific problems and probability of detection modeling.

SCOPE:

This is a new activity at Ames which will be initially designed to bring our eddy current modeling capability up to the same level as in ultrasonics. Therefore, first efforts will be directed towards assembling software packages of models already developed under Air Force and other support. After various tests are completed, the models will be extended through in-house research as needed. During the second year of the program, they will be integrated into a software framework for predicting such NDE system performance characteristics as probability of detection (POD) and sizing accuracy and into the development of a probe design capability.

APPROACH:

First Year's Effort. The program will initiate with the establishment of modeling and laboratory measurement capabilities for flaw detection and sizing. This will draw heavily on work which has been done elsewhere, particularly under AF and EPRI support. The modeling effort will include analytical approaches (1,2) valid in various frequency regimes as well as finite element codes (3-5) which achieve greater generality at the expense of increased computational complexity. They will be set up to span the full range of flaw size to skin depth ratios and formatted for application to pulsed or continuous wave measurements.

The experimental capability will consist of a state-of-the-art eddy current instrument, probes, and reference flaw set. In addition, an apparatus will be set-up to measure the magnetic fields established

by the probes in the presence and absence of an adjacent metal surface. Such reference data bears the same relationship to application of the models in real experimental situations as does the recording of waveforms reflected from a planar surface in ultrasonics.

After experimental confirmation, the models will be applied to the problem of probe design. The models for eddy current probe fields will be integrated with those for field flaw interactions to produce a model-based software package applicable to probe evaluation and design. This will allow either the predicted probe fields to be compared with those required for optimal detectability in order to assess the capability of a given probe or to vary probe geometry and frequency parameters to get a best fit to desired response. The outcome of this work will provide an engineering approach for probe design that will produce a probe optimally suited to the detection of a specified "critical" flaw.

Second Year's Effort. During the second year of the program, the model-based software for predicting probe signals of particular flaws will be extended into a probabilistic format so that predictions of probability of detection (POD) can be made. The philosophy of approach will follow that outlined in Task 2.1 for the ultrasonic case, and will make use of previous results (6,7) wherever possible.

OUTPUTS:

1. Models for predicting eddy current signals
2. Experimental techniques for characterizing the fields of eddy current probes
3. Design codes for optimizing probe parameters
4. Models for predicting POD's.

INVESTIGATORS:

V. Kogan
Student

AVAILABLE EQUIPMENT:

VAX Computers
Nortec Eddy Current Instrumentation
GR Digital Bridge
Signal Generators
Lock-in Detector

EQUIPMENT NEEDED (FIRST YEAR):

None

REFERENCES:

1. B. A. Auld, S. Ayter, F. Muenneemann and M. Riazat, in, Review of Progress in Quantitative NDE 3A, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1984), p. 489.
2. T. G. Kincaid and R. O. McCary, in, Review of Progress in Quantitative NDE 2A, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1983), p. 171.
3. B. L. Allen and W. Lord, in, Review of Progress in Quantitative NDE 3A, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1984), p. 561.
4. R. Palanisamy, R. B. Thompson and D. O. Thompson, *ibid*, p. 569.
5. R. E. Beissner and M. J. Sablik, *ibid*, p. 633.
6. J. Martinez and A. J. Bahr, *ibid*, p. 499.
7. W. Rummel, R. Rathke and R. Schaller, *ibid*, p. 467.

BUDGET PLAN (FIRST YEAR)

PROJECT 2. NDE SYSTEM DESIGN AND COMPONENT INSPECTABILITY

TASK 2.2. DEVELOPMENT OF EDDY CURRENT MODELS FOR
FLAW DETECTION AND CHARACTERIZATION

INVESTIGATORS:

EC Engineer	50.0%
V. Kogan	50.0%
1 Student	

Wages and Salaries	\$ 43,910
Benefits	8,128
Materials and Services	5,000
Travel	2,000
Computer	1,000
Equipment	0
Indirect Costs*	0
	<hr/>
Total Expenses	\$ 60,038

*Cost shared by ISU.

TASK 2.3. APPLICATION OF NDE SYSTEM DESIGN TECHNOLOGY TO ASSESSMENT OF TRADE-OFF RISKS

OBJECTIVE:

To apply model-based NDE system design technology to the analysis of risks associated with inspection of specific component designs.

SCOPE:

This task will apply the model-based NDE system design software developed in tasks 2.1 and 2.2 to selected component designs. Initially, several component designs will be solicited from Center participants for analysis. Included in the design information will be the expected defect types and critical flaw dimensions based upon the design specifications. Candidate NDE systems will be chosen for each design. For each component design and candidate inspection system, the NDE design software will be used to evaluate the given inspection system's capabilities in terms of POD's and other figures of merit. This information will be incorporated with other trade-offs, such as NDE system cost, cost of possible component failure due to false accepts, and costs incurred because of the possibilities of rejects. These are the data required to assess the applicability of a given NDE inspection system in an engineering application. There will be no effort during the first year of the program. During the second year, an ultrasonic problem will be selected and during the third year an eddy current problem will be undertaken.

BACKGROUND:

Selection of appropriate NDE inspection systems is currently a difficult problem which is compounded by the need to inspect parts of complex shapes. In the past, such selection has been made on the basis of trials performed on expensive and statistically inadequate experimental samples. In order to overcome these inadequacies, application of model-based NDE system analyses is finding increasing use. One example where this approach has been successful is ultrasonic detection modeling for cracks in nuclear reactor components performed by the Central Electricity Generating Board (CEGB) in Great Britain (1). However, to date, such an approach has not been successfully

adopted for use in the United States. Fortunately, a considerable knowledge base for modeling of inspection phenomena associated with both ultrasonic and eddy current techniques (2) has been developed and work in these areas is continuing.

APPROACH:

Second and Third Year Efforts. The purpose of this task will be to apply model-based NDE system design technology to the assessment of risks (and costs) associated with inspection system selection trade-offs for specific component designs of generic shapes. Included in the designs will be data concerning material properties, critical flaw sizes based upon fracture mechanics analysis, and expected defect population (type, location, etc.), if available. Candidate NDE inspection systems will then be chosen for each component design. Each NDE system will be analyzed by the NDE system design software developed in the preceding task in order to determine optimal operation protocols (scan increments, e.g.) and then to obtain a figure of merit for the system. To arrive at a figure of merit, the POD for critical defect sizes will be computed over the surface of the pertinent component. This POD information will be coupled with model-based estimates of characterizability of the defects and with their fracture mechanics parameters.

This model-based assessment of the performance of a given NDE inspection system, as applied to a given component design, will then form the basis for evaluation of that system compared to others selected for that component. Based on that assessment, it will be possible to estimate system costs against the costs associated with falsely accepting defective components or falsely rejecting good ones. Also, the probability of falsely accepting a defective component will entail an additional risk associated with liability incurred by component failure that can be included in the trade-off analysis. The compilation of this work should provide the design engineer with a way to select inspection techniques for a given component.

During the second year of the program, the components selected will be amenable to ultrasonic inspection since the relevant models

will have been completed at the end of the first year in Task 2.1. This will be extended to eddy current techniques in the third year.

OUTPUT:

Software to predict the risk and cost of selecting one NDE system over another for a specific component design.

REFERENCES:

1. J. M. Coffey, Review of Progress in Quantitative Nondestructive Evaluation 3A, (Plenum Press, New York, 1984), p. 1.
2. Volumes 1-4 of the Review of Progress in Quantitative NDE contain many references to models applied to detection and characterization of defects using UT and EC methodologies.

TASK 2.4 IMPLEMENTATION OF MODEL-BASED NDE TECHNOLOGY IN CAD

OBJECTIVE:

To develop a model-based software package to predict component inspectability for implementation in the CAD environment.

SCOPE:

This task will develop a CAD-implementable software package for component inspectability. Input to this package will consist of component geometry, critical defect types and sizes, material properties and proposed NDE inspection system. The geometry and defect characteristics are the typical design quantities determined by intended component use, performance requirements and fracture mechanics. The new design element, the NDE system model, is the ultimate use of NDE modeling applied to component inspectability. The goal of this task is to provide a practical, implementation ready means to guarantee component inspectability in the design stage.

BACKGROUND:

At the present time, the design of a new component is typically governed by its intended use and by fracture mechanics to ensure damage tolerance. However, little attention is paid to design characteristics which would guarantee the inspectability of the component for defects deemed critical by fracture mechanics. This typical design approach does not, thus, rule out the possibility of uninspectable components. For purposes of this work, uninspectability is defined as the case in which the probability of detection of a critical flaw becomes unacceptably low for a given inspection system and component design. The lack of design considerations for inspectability has been due, for the most part, to the inability to reliably predict the performance of NDE inspection systems. However, recent developments in mathematical modeling of the aspects of inspection phenomena now make such considerations available to the design engineer.

APPROACH:

Third Year's Effort. The goal of this task will be to produce an implementation ready software package incorporating model-based

routines which predict NDE inspection system performance assuming a specific component geometry, a description of the defects which need to be classified, and a given NDE system. The building blocks of this package will consist of the models of NDE system aspects described in the preceding tasks - models for probe radiation patterns, effects attributable to complex geometries, probe field interactions with various classes of defects, noise mechanisms, etc. For the assumed input of component geometry, defect classification and NDE system characteristics, the software will predict POD and defect characterization capability over the surface of the component. This data will be displayed graphically to allow the design engineer to assess inspectability and to make new design changes based upon both performance and inspectability parameters.

It is not anticipated that these major goals will be realized in a one year effort, and continuation into future years beyond the time frame of this Prospectus is anticipated. It is expected that significant progress on a relatively simple problem can be made during this third year.

OUTPUT:

CAD-implementable software package to predict inspectability of a specified component design.

PROJECT 3: X-RAY AND MAGNETIC NDE TECHNIQUE DEVELOPMENT**OVERVIEW:**

This project contains tasks that are aimed at the further development of NDE techniques in x-radiography and testing techniques for ferrous materials. X-rays are, of course, a widely used industrial technique in which many advances have been made in recent years; yet, there remain important advances to be made that will enhance industrial application significantly. Magnetic techniques have been explored and utilized in various ways; however, insufficient work has been done to determine the effects of some material properties upon these techniques and their ability to detect and classify defect structures and selected material properties. These tasks are designed to produce outputs of direct value to industrial users.

Two tasks in x-radiography are included in this project. They address topics in image processing and ways to reduce storage requirements and to increase processing speed. This work makes use of various signal processing treatments that have been successful in other technology areas in producing enhanced image quality (cf. references Tasks 3.1 and 3.2). The x-ray work represents an extension of the NDE capability at ISU into a very important area. It will be further enhanced by the addition of an additional staff member as described in the Prospectus. A search for suitable candidates has been initiated.

The task on the development of NDE techniques for ferromagnetic steels makes use of a new approach utilizing a newly acquired magnetic testing facility. One of these involves the use of magnetization measurements (1) while the other utilizes new Barkhausen effect devices (2) in conjunction with other measurements to determine selected material properties of technological importance.

REFERENCES:

1. D. C. Jiles and D. L. Atherton, J. Phys. D 17, 1265 (1984).
2. W. A. Thiener and I. Altpeter, in, "New Procedures in Nondestructive Testing", P. Holler (Springer-Verlag, 1983).

TASK 3.1. X-RAY IMAGE PROCESSING

OBJECTIVE:

To improve methods of extracting information from x-ray images.

SCOPE:

In this task investigators will acquire and develop hardware and software suitable for x-ray image analysis. This equipment will be general purpose in nature contrasted to a facility made for inspection purposes on a production line. Where possible, existing software will be acquired, especially for start-up. Subsequently, new algorithms and codes will be generated for use in the Center in formats suitable for use by supporting industries. Emphasis will be placed on improving procedures which aid in extracting information from data which is used for decision making.

BACKGROUND:

Images can suffer from various defects caused by the hardware used to generate the signals and to collect the data. We propose to apply our knowledge of techniques developed and proven in engineering and astronomy to x-ray analysis and to implement those techniques which prove to be better than techniques currently used.

Information extraction often depends upon some explicit or implicit model. The so-called maximum entropy method (MEM) has advantages in choosing a model which is most likely to best represent the signal component of the data. Although it is about 12 years old, MEM has been an elusive procedure to fully understand. Today, understanding has reached the point where significant gains may be made in its application to image processing.

Another procedure which has been quite important in information extraction from images is edge detection. The objective of edge detection is to detect the presence and location of changes in grey-levels describing variations in material density. Present methods are divided into two classes, frequency-domain methods and spatial-domain methods. The frequency-domain technique is based on modification of the spatial Fourier transform of an image by a high-pass filter. Edges can then be sharpened by increasing the cut-off frequency of the filter. In contrast, spatial-domain techniques are based on the magnitude of the discrete gradient corresponding to a pixel

which measures the difference in intensity levels among the pixels. Edges are then sharpened by changing the threshold procedures defining the intensity changes. Because of the simplicity and yet effectiveness of spatial-domain techniques, they are predominantly used in practical applications. Since grey-level changes in successive regions are often times minimal, enhancement techniques are needed to properly define the contour boundary for significant contrast.

Noise exists in every image. Significant features about a material can be obscured by this noise. Hence, there is a never ending need to improve techniques for extracting information from noisy data. These techniques often require various manipulative procedures of array data which form the image. A method developed in control system theory that has contributed to many areas of signal processing is Kalman filter theory. If a noise process can be properly modeled, the Kalman filter can extract a signal from the noise that other procedures cannot.

APPROACH:

First Year. Our plan is to first apply those signal processing techniques which could produce the earliest benefits. Other methods, requiring more development time, will be added later to form a continuum from short term-quick payoff projects to the longer term and more speculative projects. However, the latter will be applied research, and not basic research, projects.

During the first year, the utilization of edge detection procedures, correlations and spectral techniques will be investigated to determine their value in image improvement. Image improvement obtained in this way will then be compared with the original image, and decisions made as to which techniques are the most beneficial. We have obtained permission to use x-ray films from a local industry for this work. These films, which represent state-of-the-art commercial film radiography, will first be digitized and will form the data base for the above investigations.

We also plan to study and characterize the noise properties of the digitized x-ray images. Noise models will then be developed, giving results that can be put into algorithms that discriminate against the noise. These noise models will then be utilized with

a Kalman filtering procedure which should sharpen the image by producing a new image with less noise. At this point, standard procedures for extracting information will be applied.

Second and Third Year Efforts. The work initiated during the first year will be continued as necessary to establish the degree of image improvements obtained by the listed procedures. During the second and third years, further image improvement will be sought by introducing source deconvolution into the processing. This step should further reduce blurring and image sharpness.

The use of maximum entropy methods will also be examined. Maximum entropy has the effect of producing "super resolution", either spatially or temporally. Features can be extracted from images processed by maximum entropy that might be undetected with Fourier techniques. Unfortunately, the results are more difficult to quantify.

Consideration will also be given as to ways to produce a 3-D image without rotating the inspected component. Incoherent sources, such as those that emit x-rays, will have a particular coherence length. If one can arrange detectors in particular geometries and record data about the coherence of the scattered signal, it may be possible to reconstruct a three-dimensional image.

OUTPUT:

A set of algorithms for enhancing and extracting information from x-ray images. The procedures and computer software packages will be in languages transportable to industries, and rigorously documented so that they can be tailored to specific applications.

INVESTIGATORS:

J. Basart
S. Russel
3 Students

AVAILABLE EQUIPMENT:

Computers (ISU Computation Center, VAX, Others)

EQUIPMENT NEEDED (FIRST YEAR):

Video Camera and Digitizer
Signal Processing Software

BUDGET PLAN (FIRST YEAR)

PROJECT 3. X-RAY AND MAGNETIC NDE TECHNIQUE DEVELOPMENT

TASK 3.1. X-RAY IMAGE PROCESSING

INVESTIGATORS:

J. Basart	12.5%
S. Russell	12.5%
2 Students	

Wages and Salaries*	\$ 12,350
Benefits	3,087
Materials and Services	1,500
Travel	1,000
Computer	1,000
Equipment**	30,000
Indirect Costs***	<u>0</u>
Total Expenses	\$ 48,937

*Assumes one graduate assistant salary paid by ERI.

**Items requested:

Video camera and digitizer for x-ray images	\$ 20,000
Signal processing software packages	<u>10,000</u>
	\$ 30,000

***Cost shared by ISU.

TASK 3.2. REDUCING STORAGE OF IMAGES AND INCREASING PROCESSING SPEED

OBJECTIVE:

To develop methods for reducing the amount of storage space for x-ray images and to develop methods and hardware for increasing the speed of processing images.

SCOPE:

This task would encompass various aspects of reducing storage requirements for images. Alternate computer architectures would be studied and proposed for special purpose NDE analyzers. Increased processing speed is essential in real-time applications such as production line testing. As NDE procedures improve they are often accompanied by an increase in the amount of data and in the amount of information to be extracted from the data. This task would study these needs and suggest methods for meeting them.

BACKGROUND:

Images contain a lot of information. X-ray images with their high resolution and consequent large number of pixels can especially consume a lot of storage space. This is true both for images stored on film and for images stored on magnetic disks or tapes. There is a need for reducing data storage to save money and space. Techniques can also be developed that will process sparse images. This will allow faster processing because meaningless data are ignored.

As techniques improve in NDE methods for data acquisition, they often lead to an increase in the amount of data. Regardless of the adequacy of previous storage and analysis procedures, the new techniques continually demand improvements in data storage and processing capability.

APPROACH:

First Year. Images often contain information which can be completely useless for NDE purposes. For example, if a bicycle wheel were to be x-rayed from the side, most of the image would be empty space. In this extreme example, clearly the storage space could be vastly reduced by eliminating the empty space in the image. Of course, when the image is to be viewed or analyzed, one needs to know the proper spatial relationship of the relevant members.

Our edge-enhancement research in Task 3.1 will be applicable for defining regions to be eliminated. Once a useless region is defined, we will record the pixel locations where the empty space starts and stops in a horizontal scan. If the storage space for the start and stop pixels is less than the storage space for the empty space, one can reduce storage by eliminating the empty space. Display and analysis algorithms will be developed to handle the missing pixels.

Another method of reducing storage space that will be exercised is the substitution of a reference image from the image under analysis. Common information of no interest would subtract out, leaving the relevant information. We propose to study the practical aspects of this possibility.

Second and Third Year. Work in the second and third years will be focussed on ways to increase processing speed. If the number of pixels in an image is reduced, processing time can be reduced because there are fewer data to manipulate. Algorithms will be developed which can process data which have pixels eliminated.

Processing speed can also be increased by employing new hardware technology. Very high speed integrated circuit and very large scale integrated circuit (VLSI) technologies are continuing to produce circuits on a chip which have more signal processing capability. An integrated circuit designed for performing the fast Fourier transform algorithm, for example, can substantially reduce the processing time because processing with hard wired functions is faster than processing in software. We propose to provide a continuing review of new integrated circuits as they are developed by manufacturers and determine the benefits to be gained by building special purpose hardware NDE processors based upon them.

OUTPUT:

1. Analyses of special purpose processors for NDE which would be faster and/or friendlier than general purpose processors. In some cases, prototypes of the processors would be constructed.

2. Develop techniques and algorithms for reducing the amount of data storage required by sparse images, and for analyzing these images. These procedures would be fully documented and transportable to industry.

INVESTIGATORS:

J. Basart
S. Russell
Student

AVAILABLE EQUIPMENT:

Our current research in image processing techniques involve several computer systems on the Iowa State University campus. Our principle machine is the AS/6 at the ISU Computation Center.

EQUIPMENT NEEDED (FIRST YEAR):

None (cf. Task 3.1)

REFERENCES:

1. G. E. P. Box and G. M. Jenkins, Time series analysis: Forecasting and control, 2nd Ed. Holden-Day, San Francisco, CA, 1976.
2. R. G. Brown, Introduction to random signal analysis and Kalman filtering, John Wiley and Sons, New York, 1983.
3. B. G. Clark, "An efficient implementation of the algorithm CLEAN", *Astron. Astroph.*, 89, 377-378.
4. J. Hogbom, "Aperture synthesis with a non-regular distribution of interferometer baselines", *Astron. Astroph. Suppl.*, 15, 417-426, 1974.
5. W. Q. Meeker, Jr., "Tseries--a user-oriented computer program for time series analysis", *The American Statistician*, 32, 3, 1977.
6. R. Nityananda and R. Narayan, "Maximum entropy image reconstruction --a practical non-information-theoretic approach", *J. Astroph. Astron.*, 3, 419-450, 1982.

BUDGET PLAN (FIRST YEAR)

PROJECT 3. X-RAY AND MAGNETIC NDE TECHNIQUE DEVELOPMENT

TASK 3.2. REDUCING STORAGE OF IMAGES AND INCREASING
PROCESSING SPEED

INVESTIGATORS:

J. Basart	12.5%
S. Russell	12.5%
1 Student	

Wages and Salaries	\$ 24,350
Benefits	3,237
Materials and Services	1,500
Travel	1,000
Computer	1,000
Equipment*	0
Indirect Costs**	0
	<hr/>
Total Expenses	\$ 31,087

*See Task 3.1.

**Cost shared by ISU.

TASK 3.3. MAGNETIC INSPECTION METHODS FOR NONDESTRUCTIVE EVALUATION OF FERROMAGNETIC STEELS

OBJECTIVE:

To provide a reliable, quantitative method of nondestructive evaluation of ferromagnetic materials, particularly steels, by investigating the influence of such factors as stress, chemical composition and previous thermal treatment on their magnetic properties. Furthermore, to utilize the results of these investigations to develop devices which can be used in the field for the determination of material properties.

SCOPE:

The investigation would involve the use of the recently developed microcomputer controlled hysteresis graph facility to study the magnetic hysteresis and anhysteretic magnetisations of the materials of interest. Magnetic Barkhausen measurements will be used as a complementary technique, since this gives additional information on the microstructure of the materials. Mathematical modelling of the magnetic behavior according to the methods developed by Atherton et al. for the Canadian Department of Energy Mines and Resources would allow the determination of the various stress-related and composition-related parameters to be determined. Consideration will be given to laboratory scale experiments of potential industrial applications in order to develop expertise in the applications of the method.

BACKGROUND:

It is well established that such factors as mechanical treatment, chemical composition and thermal history have a marked effect upon the magnetic properties of ferromagnetic materials (1). However, the use of quantitative magnetic methods of nondestructive testing has lagged far behind other techniques such as ultrasound.

In recent years, there has been an enormous growth in literature on magnetic techniques from the Soviet Union (3) which has established them as leaders in this field. Lately, too, there has been considerable progress in Canada in the use of magnetic techniques for in-service inspection of gas pipelines by Trans Canada Pipelines Ltd. (4) and

various studies commissioned by the National Research Council of Canada (5). Finally, in Great Britain there have been extensive investigations by British Gas (6) and by the University of Durham (7). These investigations have led to the development of magnetic inspection devices based on a number of magnetic techniques. These include Barkhausen effect devices, magnetic flaw leakage, exterior metal loss detectors, the "stress shadow" method (8), and crack detectors based on eddy currents. The Canadian group has also recently developed a very simple "differential Hall probe" for detection of stress in steel pipelines.

Recent work in magnetic techniques (8,9,10,11) has provided an explanation of the seemingly complex and contradictory results of earlier workers (12,13). This work has shown that, in principle, it is now possible to use magnetic methods in order to determine stress in ferromagnetic materials. Furthermore, the insights provided by this work have enabled the results of magnetic surveys of pipelines to be interpreted (14). Although this is really an application which is still in its infancy, there is nonetheless considerable room for progress considering the commercial importance of iron and steel. Extension of these interpretive studies would be of enormous economic value.

In Germany, Thiener and co-workers have developed Barkhausen effect devices (15) for the determination of residual stress in ferromagnetic materials. They have found that, in general, it is best to combine several nondestructive techniques such as Barkhausen measurements, magnetization, hardness and x-ray measurements in order to determine the microstructural properties of their materials.

APPROACH:

Recently, two magnetic testing facilities have been built at the Ames Laboratory. One of these involves the use of magnetization measurements and the determination of incremental permeability using particularly desirable quantities from the viewpoint of nondestructive evaluation. The other facility utilizes the Barkhausen effect. Both of these facilities will be made available to the NDE Center.

First Year. During the first year work will be concerned primarily with the characterization of materials which are deemed to be of

particular interest to those industrial organizations involved in the Center. The characterization of the magnetic mechanism of these materials under a variety of conditions of stress, temperature and heat treatment will be an essential prerequisite for the interpretation of measurements planned for the second and third years and in the design of magnetic NDE devices. Since the facilities have already been constructed for this phase of the work, it is anticipated that this part of the work will commence with a minimum of delay and at minimal cost.

Second and Third Years. We plan to explore the effects of geometrical defect structures on the above-described magnetic measurements. One of those that is likely to produce measurable effects is porosity. Efforts will first be made to observe and understand the effects of porosity; steps will then be taken to develop a quantitative measure of the porosity volume fraction from the magnetic measurements. It is probable that other fabrication defects will also be detectable with these measurements. Efforts will be made to procure samples of ferromagnetic materials that are known to contain well-defined defects.

After developing the measurement techniques and characterizing it in terms of sensitivity to various defect structures, efforts will be concentrated on the development of devices suitable for making the necessary measurements in non-laboratory situations. The results obtained will be compared with the data already obtained during the characterization of the materials to monitor performance of the devices. Various groups have already devised some prototype devices for the detection of cracks in ferromagnetic materials (16) under laboratory conditions. Final device designs and prototypes produced in this task will incorporate elements of these as appropriate to produce industry desired measurement techniques.

OUTPUT:

The results of this task should establish new concepts in the measurement and characterization of properties and flaws in ferromagnetic materials. It is expected that the results will lead to the design of a new, fieldable NDE technique for ferromagnetic materials.

INVESTIGATORS:

D. C. Jiles
Student

AVAILABLE EQUIPMENT:

Magnetic Hysteresis Graph MH-10
(Gaussometer, integrating flux meter, x-y recorder)
Large Magnetic Power Supply (50A)
Two Solenoids (1700 Gauss)
Electromagnet
2 Desk Top Computers
Dual Channel DA Convertors
Instron Tester and Cryostat

EQUIPMENT NEEDED (FIRST YEAR:

None

REFERENCES:

1. Bozorth, R. M., "Ferromagnetism", Van Nostrand (1951) (Chapter 13).
2. Review of Quantitative NDE, San Diego, USA, July, 1984.
3. There are numerous papers which have appeared in the Soviet Journal of NDE on magnetic techniques for stress determination since 1969. There are too many to reference individually.
4. Atherton, D. L. et al., "The development of an above-ground stress measurement method", International Conference on Pipeline Inspection Methods, Edmonton, Canada, June 1983.
5. Atherton, D. L. and D. C. Jiles, "Investigation of the effects of mechanical stress on the magnetic properties of pipeline steels for pipeline stress monitoring", National Research Council of Canada (IMRI), Report No. 1. SU81-00265.
6. Clerehugh, J., Review paper on progress in pipeline inspection methods by British Gas, International Conference on Pipeline Inspection Methods, Edmonton, Canada, June, 1983.
7. Szpunar, J. and B. Azpunar, IEEE Trans. Mag., MAG-20, 1882 (1984).
8. Atherton, D. L., NDT International, June 1983.
9. Atherton, D. L. and Jiles, D., IEEE Trans. Mag., MAG-19, 2183 (1983).

10. Atherton, D. L. and D. Jiles, J. Appl. Phys. 55, 2115 (1984).
11. Jiles, D. C. and Atherton, D. L., J. Phys. D., 17, 1265 (1984).
12. Craik, D. J. and Wood, M. W., J. Phys. D., 3, 1009, (1970).
13. Cullity, B. D., Journal of Metals, 23, 35 (1971).
14. Atherton, D. L., et al., IEEE Trans. Mag., MAG-19, 1564, (1983).
15. Thiener, W. A. and Altpeter, I., in, "New Procedures in Nondestructive Testing", by P. Holler (Springer-Verlag, 1983).
16. Teller, C. M., Barton, J. R., Matzkanin, G. A., Kusenberger, F. N. and Beissner, R. E., Journal of Engineering Materials and Technology, 102, 50, (1980).

BUDGET PLAN (FIRST YEAR)

PROJECT 3. X-RAY AND MAGNETIC NDE TECHNIQUE DEVELOPMENT

TASK 3.3. MAGNETIC INSPECTION METHODS FOR NONDESTRUCTIVE
EVALUATION OF FERROMAGNETIC STEELS

INVESTIGATORS:

D. Jiles	25.0%
1 Student	

Wages and Salaries	\$ 18,688
Benefits	1,822
Materials and Services	1,000
Travel	1,000
Computer	1,000
Equipment	0
Indirect Costs*	0
	<hr/>
Total Expenses	\$ 23,510

*Cost shared by ISU.

PROJECT 4. NDE OF CERAMICS AND COATINGS

OVERVIEW:

The nondestructive evaluation of ceramic components is crucial to their successful use in applications where either thermal or mechanical loads are present. This constitutes a significant fraction of ceramic applications because they are often selected because of their good mechanical properties at elevated temperatures. Both surface or internal flaws must be detected and evaluated, with their relative importance depending on the application. Because of the brittle nature of the materials, critical flaw sizes are typically quite small, ranging upward from 50 μ m or less. In many cases, the surface geometries are also quite complex.

It is well established that ultrasonic techniques and new μ -focus x-ray techniques have a major role to play in ceramics inspections because of their penetrating abilities and sensitivity to small defects. They do not, however, provide a capability for the convenient characterization of material properties as well as defected structures. In this project, the newly emerging, complementary technology of thermal wave imaging and analysis will be examined. The physical ideas are quite straight forward. A spot on the surface is heated by a periodically modulated laser beam. A temperature pattern is set-up which is a function of the modulation frequency, the thermal properties of the material, and any defects which would alter the flow of heat. This temperature pattern can be detected by a variety of means.

Many of the operational characteristics of thermal imaging techniques are not known; in fact, the optimum configurations have not yet been fully established. However, a few conclusions can be drawn. Since the thermal energy satisfies the diffusion equation, there are many analogies to eddy current flaw evaluation in metals. Sensitivity will be greatest to near surface flaws, penetration is controlled by frequency, and considerable size and shape information is available. Since the exciter and detector can be focussed, higher resolutions can be expected than with eddy currents and operation on complex geometries should be possible. Consequently, it appears likely that thermal techniques will play an important role in the NDE of ceramics and coated materials.

This project consists of one task which will explore these opportunities. X-ray and ultrasonic tasks would also be appropriate. Anticipated resources would not allow their initiation at this time, but activities included in other projects are relevant to ceramic inspection as well.

TASK 4.1. THERMAL-WAVE MATERIALS ANALYSIS

OBJECTIVE:

To develop improved thermal-wave methods to detect surface and subsurface imperfections in materials with emphasis on ceramics. Detection is based on imaging local thermal property variations between imperfect and defect free material.

SCOPE:

This task will include establishing state-of-the-art thermal-wave imaging instrumentation, studying the detection and characterization of generic bulk materials and coatings problems to establish instrumentation capabilities, and conducting industrial collaborations to characterize specific materials and refine methods as appropriate for industrial uses. Emphasis will be given primarily to the detection and characterization of surface and subsurface defects in ceramics and secondarily to composite materials and components. Techniques will be developed to handle complex component geometries, to detect and interpret flaws with greater sensitivity, and to enhance image presentation formats to allow rapid, unambiguous identification of flaw signatures.

BACKGROUND:

The physical and chemical integrity of coatings and surface regions of bulk materials are often crucial factors in satisfying component performance requirements. Although new technologies have achieved successes in meeting increasingly demanding specifications, more sophisticated surface and near surface evaluation techniques are needed to test conformity to these specifications.

In the past five years, a unique nondestructive approach for such evaluations has been in the exploratory research stage (1,2). The approach involves correlating material properties to a specimen temperature response map which is formed when focussed energy pulses (from a laser or other source) are raster scanned over regions of interest. The resulting two dimensional image (often displayed in a grey scale format) that can be generated with the temperature response data is referred to as a thermal-wave image. The term thermal-wave refers to the temperature disturbance (resulting from thermalization of focussed pulsed energy) that propagates in the specimen and adjacent material (3). For instance, regions of amorphous

versus crystalline material can be distinguished by the higher temperature fluctuations or thermal-wave amplitudes that occur when lower thermal conductivity amorphous regions are scanned (4).

Thermal-wave images have been shown, under a variety of specimen and experimental conditions, to contain information on material properties. These properties include coating thickness and adhesion failure (5), chemical composition (6), variations in crystallinity (4), density, stress (7), and hardness (8), and the presence of fractures (cracks) (9). This is the type of information often needed to predict or diagnose component failure. However, before it can be effectively employed by industry, experiments are required to evaluate quantitative capabilities, industrial compatible measurement configurations, signal/noise optimization, and the best ways to process and to present image data in order to enhance correlations with material properties of interest and to minimize image artifacts due to irrelevant property variations.

APPROACH:

A three element approach will be pursued that includes establishing a state-of-the-art instrumentation capability, conducting exploratory studies to document instrumentation capabilities for a range of materials and flaw types, and collaborating with industrial groups on specific studies.

First Year Effort. Emphasis in the first year will be placed on upgrading current thermal-wave instrumentation to allow spatially localized detection at the specimen surface of laser excited thermal-waves. Localized detection will be based on thermally induced deflection of a probe laser beam that is sensed by a position sensitive photodiode. This mode of detection allows enhancement of thermal-wave signatures associated with cracks, noncontact remote imaging of material flaws, and operation over a wide frequency band and consequently over a wide depth and spatial resolution range.

The instrumentation upgrading effort will also involve the development of an interface for an IBM 9000 Laboratory Computer which will serve as a work station for display and manipulation of images. Finally, the existing laser and scanning systems will

be mounted on a dedicated optical table to allow flexibility for a variety of measurement configurations.

Capabilities of the upgraded instrumentation will be documented in measurements on test specimens of various materials with known flaw characteristics. These measurements are an important complement to calculated predictions of instrument performance because the thermal and other data necessary to calculate thermal-wave detection sensitivity to a given flaw are usually not accurately enough known for unambiguous predictions. The measurements on test specimens also afford the opportunity of gaining experience in optimizing detection and display parameters for specific material and flaw types. Specimen types of particular interest in this exploratory work are bulk ceramics and plasma spray and powder coatings which will be examined in the bulk case for the presence of fractures and variations in surface hardness, stress, and crystallinity. In the coatings case the objective is to image cracks and variations in coating thickness, density, and adhesion. Specimens examined in the first year will be in the form of planar or other simple geometries and will include some in this category from industrial sponsors.

Second and Third Year Efforts. In the second and third years of the task the problem of imaging more complicated specimen geometries such as cylinders will be addressed. New methods for thermal-wave signal generation, detection, and display will also be investigated as needs develop. Candidates include real-time imaging (10), IR emission detection (11), and mapping a readable flaw pattern back onto the specimen using a laser sensitive thin layer recording medium. The method of real-time signal generation and detection may prove useful when imaging speed rather than signal-to-noise and resolution are paramount. This method involves rapidly sweeping an unmodulated CW laser heating beam across the specimen to form line scan images of the thermal response. Reductions in imaging time by a factor of 10 to 100 appear possible which is significant given the slowness of the conventional thermal-wave imaging process.

IR emission detection of thermal-wave responses is an interesting candidate for study because it affords the opportunity of obtaining thermal property as well as IR spectroscopic information if the spectrum of the IR emission is measured. Hence, this method could provide chemical as well as the normal structural data in an image format.

The concept of mapping the thermal-wave image back onto the specimen via a laser recording medium could be used to facilitate reworking of components or selecting unflawed material in industrial operations. This concept is a logical exploitation of laser marking technology and the precision positioning systems associated with imaging instrumentation. An extension of this concept would be to develop a heat sensitive thin coating to use on specimens for direct recording of thermal-wave images. This approach is particularly interesting since it involves a solid-to-solid heat transfer process (solid specimen-to-solid film) that avoids the slow and inefficient solid-to-gas process (solid specimen-to-adjacent gas) that is a negative aspect of the probe beam and microphone detection methods.

The candidate areas discussed above for second and third year activities are not exhaustive. Additional candidates are expected to emerge as work progresses and interactions with industrial sponsors develop. Flexibility will be maintained to accommodate these developments.

OUTPUT:

It is expected that advanced thermal-wave imaging techniques for use with coated materials will emerge from this task. The techniques will provide both flaw and material property information. The task will provide an opportunity for Industrial Participants to conduct exploratory experiments of their own on state-of-the-art instrumentation and will provide training for graduate students and post-doctoral fellows.

INVESTIGATORS:

J. McClelland
Student

AVAILABLE EQUIPMENT:

4W CW Argon Ion Laser
300 mW CW YAG Laser
Three Lock-in Analyzers
5 Hz to 5 kHz Optical Chopper
Newport Computer Controlled Precision XY Positioning System
IBM Instruments Model 9000 Laboratory Computer

EQUIPMENT NEEDED (FIRST YEAR):

Probe Laser
Position Sensor and Optics
Image Display
Optical Table

REFERENCES:

1. See Scanned Image Microscopy, edited by E. A. Ash (Academic Press, London, 1980), pp. 247-353.
2. A. Rosencwaig, *Science* 218, 217 (1982).
3. F. A. McDonald, *Am. J. Phys.* 48, 41 (1982).
4. J. F. McClelland and R. N. Kniseley, *Appl. Phys. Lett.* 35, 585 (1979).
5. D. P. Almond, P. M. Patel, H. Reiter, *J. de Physique* C6, 491 (1983).
6. J. F. McClelland, R. N. Kniseley, and J. L. Schmit, in, Scanned Image Microscopy, edited by E. A. Ash (Academic Press, London, 1980), p. 353.
7. M. Luukkala and S. G. Askerov, *Electronics Lett.* 16, 84 (1980).
8. J. Jaarinen and M. Luukkala, *J. de Physique* C6, 503 (1983).
9. Y. H. Wong, R. L. Thomas, G. F. Hawkins, *Appl. Phys. Lett.* 32, 538 (1978).
10. R. S. Quimby, *Appl. Phys. Lett.* 45, 1037 (1984).
11. H. Ermert, F. H. Dacol, R. L. Melcher, and T. Bauman, *Appl. Phys. Lett.* 44, 1136 (1984).

BUDGET PLAN (FIRST YEAR)

PROJECT 4. NDE OF CERAMICS AND COATINGS

TASK 4.1. THERMAL-WAVE MATERIALS ANALYSIS

INVESTIGATORS:

J. McClelland	25.0%
1 Student	

Wages and Salaries	\$ 20,694
Benefits	2,323
Materials and Services	1,000
Travel	1,000
Computer	1,000
Equipment*	23,300
Indirect Costs**	<u>0</u>
Total Expenses	\$ 49,317

*Items requested:

Probe laser	\$ 1,500
Position sensors and optics	800
Image display	18,000
Optical table	<u>3,000</u>
	\$ 23,300

**Cost shared by ISU.

PROJECT 5. NDE FOR MATERIALS PROPERTIES

OVERVIEW:

The nondestructive determination of materials properties has taken on added importance in recent years. For example, the control of incoming material properties can produce significant economic advantages through removal of defective material from the production line before value-added costs are incurred. The measurement of properties to control manufacturing processes is another case in point. For these and other reasons, it is desirable that nondestructive methods be developed for the measurement of various material properties of technological importance. This project addresses two important specific cases (1). One of them is the development of a NDE scheme to sort and classify aluminum lithium alloys according to various microstructures produced by heat treatment, and the second is the development of techniques and interpretive understanding to characterize interfaces and resulting properties in joined materials.

Aluminum-lithium alloys are of industrial interest because of their low density, high stiffness, and corrosion resistant properties. Eddy current techniques (conductivity measurements) have been used with other alloys to sort and to classify them according to heat treatment, and eddy current techniques together with hardness measurements have been used in other specific cases. Work in this task is focussed on the application of both eddy current techniques and EMAT ultrasonic techniques to produce a unique classification scheme that should produce a fairly complete description of the microstructure of the alloy. Both of these techniques are "non-contact" and are compatible with production environments.

The second task is focussed upon ways to characterize the interface between materials developed by a bonding process and key properties of the resulting product. Examples of such processes include diffusion (solid state) bonding, "pinch" welding, and friction bonding. Goals of this task focus primarily upon the development of ultrasonic techniques to characterize the state of the microscale asperity population at the interface, an approach strongly suggested by both

recent theoretical and experimental advances. From a knowledge of the interface asperity conditions, estimates of "strength" can be obtained. Other interfacial properties may also be obtainable from this technique (and derived information) including a measure of rubbing friction between two components in contact.

REFERENCE:

1. R. A. Chihoski, "Nondestructive methods for material property determinations", Ed. by C. O. Ruud and R. E. Green, Jr. (Plenum, 1984), p. 81.

TASK 5.1. NONDESTRUCTIVE METHODS FOR THE DETERMINATION OF THE
THERMAL HISTORY AND MECHANICAL PROPERTIES OF
ALUMINUM-LITHIUM ALLOYS

OBJECTIVE:

To provide a reliable, quantitative method that can be used as a noncontact, on-line quality control system for determining the heat treatment (microstructure) of aluminum-lithium alloys, and to explore ways to determine selected mechanical properties of this and other materials nondestructively.

SCOPE:

There is a well defined industrial need for nondestructive techniques that can be used to select materials according to a material property specification. One specification commonly encountered is a specification for material microstructure which is developed according to specific heat treatments. For a particular microstructure, associations can then be made with other mechanical properties of the material. The scope of this task includes the development of nondestructive ways to characterize and to sort aluminum-lithium alloys of different microstructure generated by different heat treatments in ways that are compatible with a production environment, and further, to explore ways that will lead to more direct, nondestructive determinations of the mechanical properties of interest in these alloys. Examples of the latter include the yield strength, fracture toughness, and texture.

BACKGROUND:

Aluminum-lithium alloys are of significant commercial interest because they combine low density with high stiffness (1) and also possess excellent corrosion resistant properties. The alloy of principal interest contains approximately 3% lithium in aluminum by weight, and is prepared by thermal aging at prescribed elevated temperatures following an initial quench (2) from a high temperature. Alloys of different microstructures and properties, of course, result from aging at different temperatures. The quenched state, often referred to as the ω phase, contains the solute lithium atoms in solution. Thermal aging then precipitates a β phase from the ω

state. The final low temperature phase is an $\alpha+\beta$ phase in which the size of the precipitates obtained depends upon the aging temperature and the rate of cooling from the aging temperature with concomitant variations in alloy strength and hardness (3). Chihoski (4) has shown that details of the thermal history of the 2219 alloy can be obtained from a combination of conductivity and hardness measurements. These measurements have not been applied in combination, however, to other alloy systems.

Nondestructive measurements are not available to characterize directly important mechanical properties that are a consequence of the material microstructures (see several recent conference proceedings, 5-7). For example, the yield strength and fracture toughness of a material may depend on the direction of the applied stress relative to the texture direction so that the yield locus is off center with respect to the stress coordinate system. An acoustical determination of the texture pole figure is now possible. It should thus be possible to extend the characterization reported by Chihoski (4) noted above to include other measurements so that direct nondestructive measures of important mechanical properties can also be obtained directly.

APPROACH:

First Year. Aluminum-lithium alloys will be used in this investigation. The material will be selected and heat treated so that the various microstructures characteristic of this alloy are produced. The resulting microstructures will then be determined and verified using metallographic and SEM techniques as appropriate.

As a first goal, efforts will be made to devise a nondestructive material sorting scheme which will permit the various microstructure obtainable in the aluminum-lithium alloy to be sorted and characterized. Two noncontacting techniques suitable for the production environment will be employed in this work; they are eddy current methods which yield the electrical properties of the materials and EMAT ultrasonics which yield some of the mechanical properties of the material (modulus, grain size, texture). From this combination of measurements it should be possible to determine the heat treatment histories of the samples.

A commercially available eddy current instrument and peripherals (NORTEC) will be used to make the eddy current measurements. Measurements of the complex impedance of the various samples will be made over a range from 100 Hz to 3MHz. Scanning over a range of frequencies permits sampling at different depths in the material and should show any variations in microstructure as a function of material depth, a condition that might occur under rapidly cooled conditions. The complex impedances will then be correlated with sample heat treatments, a correlation that is known to exist. As an example, the resistivity is known to increase with faster quench times and with greater hardness whereas it decreases with aging time.

Initial ultrasonic measurements will be made using permanent magnet EMAT's to excite horizontally polarized shear waves (SHo waves). The shear moduli of the samples will be determined from these measurements. Any texture in the materials can also be readily detected by rotating the EMAT on the sample sheet and noting the change in the acoustic velocity (shear modulus) as a function of direction (cf Project 7). If additional information is needed to characterize the thermal histories of the samples, efforts will also be made to determine the grain size distributions as a function of aging history using the SHo EMAT or other forms of the EMAT transducer (e.g., Lamb wave).

Work will also be pursued in the first year that should lead to additional and direct nondestructive mechanical property measurements. Tensile coupons will be prepared from the same heat treatments used in the first part of this task, and will be used to determine the yield stress. Charpie-V-notch coupons will also be prepared from which the impact strength (related to fracture toughness) of the materials will be determined.

Second and Third Years. It is expected that enough information will have been collected during the first year using eddy current and EMAT measurements so that a nondestructive sorting and classification scheme for aluminum-lithium alloys can be constructed using these techniques. The scheme will then be tested using additional, "blind" samples; after measurement, the microstructure of the samples will

be determined using appropriate metallurgical procedures. From the two sets of results, it will then be possible to determine the statistical accuracy of the sorting scheme. Any needed refinement of the sorting scheme and measurement techniques will then be made.

Work will be continued in the second and third years to find direct, nondestructive measures of selected mechanical properties of the aluminum-lithium alloys and a steel whose phase diagram is well known. Results of destructive measurements made in the first year will be extended as needed and compared with the available nondestructive measurements (conductivity, ultrasonic velocity and attenuation, etc.). It is conjectured that guidance in this search will be obtained by constructing 3-D plots in which the yield stress or impact energy is plotted against two nondestructively determined properties (e.g., conductivity, hardness, acoustic velocity, attenuation, etc.). If this empirical approach appears to be successful, modeling efforts will then be undertaken to define a methodical approach to the development of nondestructive techniques to obtain direct measures of mechanical properties.

OUTPUT:

A principal output of this task will be the demonstration of a scheme to sort and classify various heat treatments of aluminum-lithium alloys. It is expected that the sorting scheme will consist of eddy current techniques possibly augmented by EMAT technology. The output will also contain an estimate of the reliability of the classification procedure.

The task will also set guidelines for the development of nondestructive techniques for the direct determination of selected mechanical properties of an alloy system such as aluminum-lithium. It is not expected, however, that this portion of the task will be completed within three years at the anticipated funding levels.

INVESTIGATORS:

Otto Buck
D. Jiles
Student

AVAILABLE EQUIPMENT:

Nortec Eddy Current Instrument
GR Digital Bridge
Lock-in Amplifier
EMAT Transducers, Pulsers, and Receivers
Heat Treating Furnaces
Mechanical Testing Equipment (MTS)
SEM
Metallographs

EQUIPMENT NEEDED (FIRST YEAR):

None

REFERENCES:

1. T. H. Sanders and E. S. Balmurth, Metal Progress, March, 32 (1978).
2. A. J. McAllister, Bulletin of Alloy Phase Diagrams, 3, 177 (1982).
3. R. Chihoski, Metal Progress, May, 27 (1983).
4. R. A. Chihoski, Nondestructive Methods for Material Property Determination, ed. by C. O. Ruud and R. E. Green, Jr., (Plenum, 1984), p. 81.
5. O. Buck and S. M. Wolf, Eds., "Nondestructive evaluation: Microstructural characterization and reliability strategies", AIME, 1981.
6. C. O. Ruud and R. E. Green, Jr., "Nondestructive methods for material property determination", Plenum Press, 1984.
7. O. Buck and S. M. Wolf, "Nondestructive evaluation: Application to materials processing", ASM, 1984.

BUDGET PLAN (FIRST YEAR)

PROJECT 5. NDE FOR MATERIALS PROPERTIES

TASK 5.1. NONDESTRUCTIVE METHODS FOR THE DETERMINATION OF THE
THERMAL HISTORY AND MECHANICAL PROPERTIES OF
ALUMINUM-LITHIUM ALLOYS

INVESTIGATORS:

O. Buck	12.5%
D. Jiles	25.0%
1 Student	

Wages and Salaries	\$ 26,789
Benefits	3,847
Materials and Services	1,000
Travel	2,000
Computer	1,000
Equipment	0
Indirect Costs*	0

Total Expenses	\$ 34,636
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*Cost shared by ISU.

TASK 5.2. ULTRASONIC CHARACTERIZATION OF METALLIC INTERFACES

OBJECTIVE:

To develop ultrasonic techniques to characterize the interface of bonded materials (metals), and to estimate important material properties of the bonded structure utilizing these techniques.

SCOPE:

This project is aimed at the development of ultrasonic techniques for the characterization of interfaces between two joined parts. These techniques have application to components joined by diffusion bonding, pinch welding, and friction bonding, and further, may be useful in nondestructive measurements of rubbing friction and (to zeroth order) bond strength. The work utilizes understanding developed in the BES Metallurgy and Ceramics Program and multiviewing ultrasonic instrumental advances made in the BES Engineering Program.

BACKGROUND:

It has recently been shown experimentally that ultrasonic reflectivity can be used to explore details of the interface between two joined materials. In one application (1), these measurements have been used to determine the radial component of stress in a shrink-fit coupler; in another, ultrasonic techniques have been shown to be useful in a characterization of the state of closure of a crack (2,3). Theoretical models have also been developed that explain the observed results (4,5). Both models attribute the behavior of the reflectivity at the interface to asperity contact between the surfaces. Thus, the surfaces are not considered ideally smooth, but are in fact held apart on a microscale by the asperities present. As the contacting stresses are increased, the asperities undergo plastic deformation and increase the area of contact thereby decreasing the magnitude of the reflectivity. Application of current models to experimental results typically yield values of a "spring constant" of the interface or, equivalently, the value of the compressive stress at the interface assuming that the surface roughness and yield properties of the base material are known. Additional information is needed to fully characterize the interface under realistic conditions that may include a planar distribution of inclusions in addition to the asperity populations (6). The asperity model has typically been used as a tool of tribology.

APPROACH:

First Year. Although considerable advances have been made in the nondestructive ultrasonic characterization of interfaces, additional information is needed in order to be able to predict important mechanical properties of the joined interfacial structure from nondestructive measurements. The approach taken in this task will focus upon the development of nondestructive techniques that will provide a characterization of the asperities at the interface and that will permit estimates of the surface density and the average contact area per asperity to be made. Work in the later part of the program will include possible inclusions (e.g., oxide) at the interfaces in addition to the asperity contacts. From this information the total amount of joined surface can be estimated. A "zeroth order" comparison of selected mechanical properties of the joined material with the unjoined host properties can then be made. Examples of properties that may be obtainable are the "strength", yield stress, and fatigue life of the joined interface.

Samples will first be designed and joined that will provide a variety of asperity contacts at the joined interface. They will be fabricated from materials of industrial interest and will include stainless steel and titanium. Sample surfaces will first be prepared with a variety of controlled and characterized surface roughnesses prior to bonding, and then they will be bonded under conditions of controlled heat and pressure. The bonding temperature will be selected so that sintering can take place in all cases, but the bonding pressure will be controlled to produce different amounts of plastic flow in the asperity structure. Representative samples will then be selected to destructively determine the characteristics of the interface.

One of the approaches taken to develop a nondestructive technique to characterize the interface will rely upon nonspecular ultrasonic scattering. This approach will probably involve both reflection and transmission experiments from and through the interface. Measurements will be made to determine the amount and spatial distribution of energy scattered from the interface as a function of frequency. It is expected that the new multiviewing transducer developed under

BES Engineering sponsorship will be utilized in this effort. After measurable effects are obtained, some modeling effort will be initiated to develop a framework in which the scattered results can be understood in terms of interfacial asperity conditions. The specific quantities that are desired include the areal density of contact points and the average area per contact.

The second approach that may have potential for generating the desired results is harmonic generation. It can be anticipated that the asperity nature of the interface may provide a nonlinear contribution to either the reflectivity or to the transmitted ultrasonic signal that can be related to the bond character. Attempts will be made to observe second harmonic generation in the samples discussed above as time and funds permit. It is possible that it may be easier to obtain a good signal/noise ratio in this case since the detection will be done at twice the transmitter frequency. If it proves possible to obtain good information from these experiments, a modeling effort will be instigated to develop a quantitative measurement technique.

Second and Third Years. Work on the development of both the experimental techniques and the associated modeling efforts initiated in the first year will be continued. As it becomes possible to obtain good measures of the asperities at the interface (areal density, average area per asperity, and perhaps the size distribution of the asperities), efforts will begin to estimate important mechanical properties of the interface including yield stress, fatigue life, and "strength". A zeroth order approach will first be taken in which these properties will be estimated assuming that the interfacial properties are degraded in the ratio of asperity contact area to total surface area. These properties will be estimated for various samples using the nondestructively determined results; actual values for the samples will then be obtained by destructive testing. It is expected that the results obtained may only be approximate, but they may also provide guidance in defining better ways to estimate properties from the measurements. Work on the preparation and measurement of samples that show inclusions at the interface (in addition to asperities) will also be initiated. Inclusions will most likely include oxides of controlled thicknesses (probably less than the

asperity heights). The experimental measurement and modeling effort is expected to proceed in the same way as the previous study using only asperity contact bonds.

It can also be imagined that the rubbing friction between two samples could be characterized by the above-described measurement techniques. This possibility will be examined as time permits.

OUTPUT:

This task will define and develop ultrasonic techniques that are applicable to the characterization of interfaces between two materials. They will be of value in characterizing the mechanical properties of bonded materials (to zeroth order) and to a measurement of rubbing friction.

INVESTIGATORS:

D. K. Rehbein

J. Smith

Student

AVAILABLE EQUIPMENT:

Multiviewing Transducer Assembly

Tektronix 7912 Digitizer

Tektronix 4052 Desk Top Computer

Display Equipment

Ultrasonic Pulsers/Receivers

Transducer Selection

EQUIPMENT NEEDED (FIRST YEAR):

None

REFERENCES:

1. D. K. Rehbein et al., Journal of Nondestructive Evaluation, 4, No. 1 (3).
2. R. B. Thompson, et al., "Effects of crack closure on ultrasonic transmission", in, Review of Progress in QNDE 2, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1983), p.325.
3. O. Buck, et al., "Simulation of closure: Effects on crack detection probability and stress distributions", *ibid*, p.345.
4. N. F. Haines, Report RD/B/N4744 Central Electricity Generating Board, Berkeley Nuclear Laboratories, Bristol, UK (1980).
5. R. B. Thompson, et al., to be published.
6. J. Baik and R. B. Thompson, "Long wavelength elastic scattering from a planar distribution of inclusions", to be published.

BUDGET PLAN (FIRST YEAR)

PROJECT 5. NDE FOR MATERIALS PROPERTIES

TASK 5.2. ULTRASONIC CHARACTERIZATION OF METALLIC INTERFACES

INVESTIGATORS:

J. Smith	25.0%
D. Rehbein	25.0%
1 Student	

Wages and Salaries	\$ 35,965
Benefits	6,141
Materials and Services	4,000
Travel	2,000
Computer	1,000
Equipment	0
Indirect Costs*	<u>0</u>
Total Expenses	\$ 49,106

*Cost shared by ISU.

PROJECT 6. NDE TECHNOLOGY FOR ADVANCED COMPOSITES

OVERVIEW:

Advanced composites, with their superior specific strength and unique physical properties that can be tailored to suit the engineering application, are becoming important structural materials of today's technology world (1). To ensure the material integrity and structural reliability of composites, a sound understanding of the effects of defects and quantitative means to detect and characterize such defects must be developed. The nondestructive evaluation of composites, both in terms of the effects of defects and the detection and evaluation, is hampered largely by the inhomogeneous and anisotropic nature of the composites (2). To overcome some of these difficulties and to advance the state-of-the-art in composite NDE, we propose a systematic study to catalog and prioritize the flaw types and their severity in composites. We plan to study the interaction of the interrogating field and the intrinsic structures in composites so that NDE techniques proven successful for homogeneous and isotropic material may be modified and extended to the case of composites. The range of applicability and the necessary modifications in utilizing such NDE methods will be identified and implemented. We also plan to develop new methods that take advantage of the material properties of composites for the detection and characterization of specific types of flaws.

Throughout the program, efforts will be made to expand the knowledge base on the effects of defects and on the detection and characterization methods by drawing on the materials science data base and the results of NDE in composite research to date. An experimental effort will be made to fabricate well-characterized defects for NDE methodology development and for the assessment of the effects of defects. In the course of the research we will study mechanical defects such as delaminations, cracks, interlaminar voids and inclusions, and impact damages. Distributed defects such as porosity and environmentally induced defects such as moisture damages will also be studied as flaws in the broader sense. As a general rule the research will progress from simple (unidirectional) systems to more complex systems such as cross-ply and quasi-isotropic layups.

The outcome of the program is expected to provide an improved understanding of the response of the composites to the probing fields and the effects of different defects on structural reliability, and more advanced and new methods for the detection and characterization of flaws in composites. Given the wide application of composite materials as critical structural components, the payoff in reliability and cost-saving of an efficient composite NDE technology base can be substantial indeed.

REFERENCES:

1. Handbook of Composites, George Lubin, Ed., Van Nostrand, 1982.
2. Nondestructive Evaluation and Flaw Criticality for Composite Materials, R. B. Pipes, Ed., ASTM STP 696, 1979.

TASK 6.1. EFFECTS OF DEFECTS IN COMPOSITES

OBJECTIVE:

To catalog the flaw types in composites and prioritize their severity by investigating the effects of defects on strength and stiffness degradation, failure mode, and fatigue lifetime of composites. This effort will help define NDE technique development.

SCOPE:

In the industrial application of composites as structural materials, a number of commonly occurring defects - either from the manufacturing process or service induced - have been identified to be of importance. Part of the NDE objective is to detect and characterize such defects (cf Task 6.2); once the flaw type is identified and the flaw parameters are determined, it is important to assess the severity of the defects based on their effects on the strength and service life. In this task we propose to broaden the data base of the effects of defects by conducting a series of experimental and analytical investigations to reach the goal of being able to prioritize the criticality of different flaws and, for a given flaw type, the dependence of the severity on the extent of the damage. The growth of defects under stress and the initiation of delamination from cracks and inclusions will be studied. The effects on strength of distributed defects such as porosity and moisture content will also be investigated. Among the advanced composite materials, attention will be given to fiber reinforced plastics because of their extensive use in both secondary and primary structures in the aerospace industry. Others will be examined later in the work.

BACKGROUND:

Defects in composite materials have important engineering significances because they often behave as stress concentrators and failure initiation sites. Such defects may originate from the fabrication process such as inclusions, porosity and trapped volatile gases evolved in the curing process of the matrix material, and fiber misalignment. Defects may also be service induced such as impact damage, cracks and microcracked zones, delamination and disbonds, and moisture damage from service in a hot and humid environment. It is known that not all flaws lead to catastrophic results and in certain cases rather large delaminations can be tolerated without serious consequences.

The purpose of an effects of defects study is to identify the detrimental flaw conditions and quantify their severity thus enabling a prioritization to be made for NDE purposes.

Two of the most complete accounts of the recent works in the area of damage development and defect effects are contained in two recent ASTM publications (1,2). Extensive studies have been made to understand and characterize the behavior of various types of defects. Both experimental investigation using mechanical testing and analytic studies using stress intensity analysis and energy release rate calculations have had some success. However, the engineering significance of the effects of defects in composites still requires further investigation.

It is well known that the fatigue lifetime of composites, unlike that of metals, shows great statistical variations. For example, the fatigue lifetime of a fabricated graphite/epoxy composite may show as many as six orders of magnitude scatter when it is subjected to flexural fatigue to failure by delamination (3). The origin of the large scatter is attributed to the variation in the type, size and location of intrinsic defects. Such scatter in fatigue life is narrowed considerably when the correlation is made to the maximum stress intensity range of the defects on the fracture plane. In this task, the emphasis will be placed on the prioritization of the severity of defects based on the flaw type, size, orientation and physical location in the composite laminate structure.

APPROACH:

First Year. In the study of the effects of defects, specimens containing known defects are an important part. During the first year efforts will be made to obtain such specimens when commercially available and to fabricate specimens containing prescribed defects for mechanical testing purposes. Three cases will be studied in the initial phase: delamination, porosity and impact damage. The delamination specimens will be fabricated following the usual practice of imbedding bonding inhibiting films in the layup process. The size, shape and location of such prescribed delaminations are easily controlled. Impact damage will be introduced mechanically and the porosity specimens will be produced by controlling the vacuum and

curing parameters in the fabrication step. The extent of the impact damage and the content of porosity will be quantified using methods already developed (4) or soon to become available (5).

The quantities to be studied in the mechanical testing will be principally stiffness reduction and the fatigue lifetime. The characteristic stiffness reduction has been used in such a manner that the sequence of damage development could be correlated to the mechanical response and to the percent of life expended (6). The fatigue life depends on the size, shape and location of the most severe flaw, in the stress intensity sense, present in the fracture plane (3). In the latter case, prescribed inclusions of controlled size and shape can be introduced in the fabrication process.

During the first year, an effort will be made to build-up the analytic and modeling capabilities for comparison with the experimental results. In particular, the boundary element method (BEM) model may offer significant improvement over finite element methods used in the modeling of crack behavior in a locally isotropic but inhomogeneous region. The BEM model treats a crack or delamination as a zero volume defect without the need for special elements or very fine volumetric meshes. The development of a 3-D BEM modeling capability will aid the study of local stress fields around interlaminar and translaminar cracks and the stresses produced by local fiber fracture and fiber-matrix debonding.

Second and Third Year. The effort in the second and third year will be in two areas: 1) based on the results obtained in the first year, the data base for cataloguing the flaw type and severity will be expanded. Mixed flaw types such as multiple delamination and delamination occurring concurrently with ply cracks or fiber breaks will be considered; 2) the question of damage development and delamination growth in the cleavage, shear and mixed modes will be addressed and fracture mechanics modeling analysis will be compared with pertinent experiments to assess the criticality of defects.

OUTPUT:

A prioritization of the severity of various types of defects in composites based on analytic modeling and experimental testing.

INVESTIGATORS:

T. McDaniels
T. Rogge
T. Rudolphi
Two Students

AVAILABLE EQUIPMENT:

Sample Fabrication: Curing Oven
Vacuum Pump
Storage Freezer

Computer Facilities
Finite Element and BEM Systems

EQUIPMENT NEEDED (FIRST YEAR):

Hydraulic Press
Oven Temperature Control

REFERENCES:

1. Effects of Defects in Composite Materials, D. T. Wilkins, Ed., ASTM Special Technical Publication 836, (1984).
2. Damage in Composite Materials, K. L. Reifsnider, Ed., ASTM Special Technical Publication 775, (1982).
3. R. J. Richards, W. L. Morris, and O. Buck, "Fatigue lifetime predictions from ultrasonically detected laminar defects in a graphite/epoxy composite", Review of Progress in Quantitative NDE, Vol. 1, p. 295 (1982).
4. S. N. Chatterjee, K. W. Buesking, B. W. Rosen and W. R. Scott, "Assessment of significance of defects in laminated composites - A Review of the State-of-the-Art", to appear in Review of Quantitative NDE, Vol. 4, 1985.
5. D. E. Yuhas and B. Patel, "Comparison of methods for determining porosity in graphite epoxy composites", to appear in Review of Progress in Quantitative NDE, Vol. 4, 1985.
6. R. D. Jamison, K. Schulte, K. L. Reifsnider, and W. W. Stinchcomb, "Characterization and analysis of damage mechanisms in tension-tension fatigue of graphite/epoxy laminates", in ASTM STP836, p. 21 (1984).

BUDGET PLAN (FIRST YEAR)

PROJECT 6. NDE TECHNOLOGY FOR ADVANCED COMPOSITES

TASK 6.1. EFFECTS OF DEFECTS IN COMPOSITES

INVESTIGATORS:

T. McDaniels	20.0%
T. Rogge	10.0%
T. Rudolphi	10.0%
2 Students	

Wages and Salaries*	\$ 34,044
Benefits	5,661
Materials and Services	2,000
Travel	3,000
Computer	1,000
Equipment**	8,200
Indirect Costs***	<u>0</u>
Total Expenses	\$ 53,905

*Assumes one graduate assistant salary paid by EMRRI

**Items requested:

Hydraulic press	\$ 5,000
Oven temperature control	<u>3,200</u>
	\$ 8,200

***Cost shared by ISU.

TASK 6.2. DETECTION AND CHARACTERIZATION OF DEFECTS IN COMPOSITES**OBJECTIVE:**

To identify the range of applicability and the necessary modifications of proven NDE methods for the evaluation of defects in composites and to develop new detection and characterization techniques.

SCOPE:

The major difficulties in the detection and characterization of defects in composites stem from the highly inhomogeneous and anisotropic nature of the composite, the large number of material and structural parameters and the material variability. The probing field used for studying the defects often also interacts strongly with the internal structures of the composite and the interpretation of the detected signals is made difficult. It is therefore desirable to identify the interrogation methods and measurement configurations that are less sensitive to the internal structures and yet interact with the defects with distinct and recognizable features. To aid the separation of the flaw response from the detected overall response, a systematic study of the interaction field (e.g., stress waves) with the internal structures of a nominally defect free composite will be made. The utilization of recent advances in elastic wave inverse scattering methods to the case of composite will be investigated and in the process the regime of applicability and modifications needed will be identified.

Composites represent unusual mixtures of materials. The development of new NDE techniques making use of recent advances in materials science is in the beginning stage and holds good potentials for future applications. In this task we will try to develop new NDE methods using new or combination of probing fields to exploit the unique material properties of composites.

BACKGROUND:

The NDE technology for traditional homogeneous and isotropic materials has gained maturity in recent years in terms of the ability to detect and characterize the defects and to predict the failure based on fracture mechanics. However, the same degree of capability is not yet available for the nondestructive evaluation of advanced composites such as fiber reinforced plastics and metal matrix composites.

Conventional NDE techniques using elastic waves, including ultrasonic scattering, inversion algorithms for flaw sizing and acoustic emission, are complicated by the presence of internal periodicities and scattering centers in the composites. Both the interrogation field and the flaw signal are modified by the internal structures, which complicate the detection and characterization of the defects. Nonetheless, traditional NDE methods have been used successfully in evaluating certain types of flaws. Ultrasonic C-scan (1) is capable of imaging delaminations of reasonable sizes and ultrasonic backscattering (2) has shown good potential for further development. Work in the detection of porosity is currently underway in the AF program. A good understanding of the response of the defects in the composite environment to the probing waves will clearly aid the transfer of well-developed NDE techniques for isotropic materials to the case of composites.

To meet the challenge of flaw detection and characterization in composite, most known NDE methods and probing fields from dye penetrant to laser holography have been explored to various degrees (3,4). Each technique has its range of applicability and limitations. For certain flaw characterization requirements, opportunities exist in making use of the material and physical properties of the constituents in the composite for the development of new NDE methods. For example, medical computed tomography has been explored in the inspection of carbon-carbon composites since the use of CT on the human body is also based on the properties of carbon (5). Similar opportunities should exist for RF electromagnetic waves and thermal waves, especially in the characterization of distributed flaws such as moisture damage in fiber reinforced plastics.

APPROACH:

First Year. The emphasis in the first year will be the adaptation of proven NDE methods to the detection and evaluation of defects in fiber reinforced plastics. A limited effort will be made to explore new NDE techniques for composites.

In recent years, a number of quantitative NDE methods have been developed for defects in metal parts. One area that has gained considerable maturity is the elastic wave inverse scattering methods. These advances include, in increasing order of frequency, the long wavelength approximation (6), the inverse Born approximation (7),

and the high frequency ray method (8). An extension of such techniques to the NDE of composites will be very beneficial. In this task we will concentrate on the long and intermediate wavelength methods to minimize the influence of the internal structures. Attempts will be made to separate the flaw signal from the internal structure signal when the latter is well defined. We will also make use of measurement configurations optimal for defect interrogation in a given composite layup. The experimental difficulties associated with low frequency measurements will be addressed using recent advances in transducer/pulser design which produces ultrasonic pulses with a richer low frequency content. Existing knowledge on rough cracks will be drawn upon, as the cracks and delaminations in composites are generally expected to have rough surfaces.

On the analytical side, we propose to extend to composites the boundary element method (BEM) model derived by Schmerr (9) and recently applied to crack scattering problems in homogeneous, isotropic materials. The BEM model will be used to solve scattering problems in composites by cracks and delaminations in the low to intermediate frequency range where heterogeneity effects are minimized. Also, this model will be employed to provide synthetic scattering data that can be used in testing inverse scattering models.

In the first year we expect to carry out some exploratory NMR experiments on a graphite/epoxy system. The use of NMR in evaluating distributed flaws such as absorbed moisture and trapped volatile gas evolved in the curing step are likely topics for the initial exploration.

Second and Third Year. Following the approach of progressing from simple systems to more complex situations, proven NDE methods will be applied to more complex composite layups and to multiple delaminations in the second and third year. The development of new NDE techniques will receive increasing attention. In applying the NMR technique to composites we hope to proceed from measurements sensitive to the presence of defects (e.g, moisture) to develop methods capable of measuring the amount of moisture and the moisture content profile (governed by the diffusion equation) in the composite. We shall also explore other new detection and characterization techniques and include here two such examples: 1) by viewing the graphite

fibers in a graphite fiber reinforced plastic as embedded internal resistors, one may pulse some of the fibers with an electrical current and use the sudden thermal expansion and the accompanying elastic waves as an internal source for acoustic emission studies, and 2) eddy current and electrical conductivity techniques will be considered in the evaluation of the fiber contact conditions and the electrical conduction transverse to the fibers (governed by a percolation mechanism) (10) could be used in the characterization of the moisture induced expansion of the host matrix.

OUTPUT:

We expect Task 6.2 to produce improved understanding of the elastic behavior of the internal structure of composites which is essential to the development of flaw detection and characterization methods. Measurement configurations most immune to the interference of the intrinsic structures will be identified and proven NDE methods for conventional materials will be modified and applied to the case of composites. We also expect this task to produce new detection and characterization techniques based on the material properties of composites and applicable to specific classes of defects.

INVESTIGATORS:

D. K. Hsu
Student

AVAILABLE EQUIPMENT:

NMR Spectrometer
Ultrasonic System: Immersion Tank
DPO
Pulser/Receiver
4052 Desk Top Computer
Computation: Vax Computer

EQUIPMENT NEEDED (FIRST YEAR):

Precision Goniometer
Polisher
Optical Meter

REFERENCES:

1. R. A. Blake, "Quantitative pseudocolor C-scan evaluation and enhancement", Review of Progress in Quantitative NDE, 3B, p. 1051 (1984).
2. Y. Bar-Cohen and R. L. Crane, "Acoustic backscattering image of subcritical flaws in composites", Materials Evaluation 40, 970 (1982).
3. S. N. Chatterjee, K. W. Buesking, B. W. Rosen, W. R. Scott, "Assessment of significance of defects in laminated composites - A Review of the state-of-the-art", to appear in Review of Progress in Quantitative NDE 4, (1985) (and references therein).
4. "Symposium on NDE of criticality of defects in composite laminates", valley Forge, PA, May 23-24, 1983.
5. K. D. Friddell, A. R. Lowrey, and B. M. Lempiere, "Application of medical computed tomography (CT) scanners to advanced aerospace composites", to appear in Review of Progress in Quantitative NDE, 4, (1985).
6. B. Khuri-Yakub, G. S. Kino, and A. G. Evans, "Acoustic surface wave measurements of surface cracks in ceramics", J. Am. Ceramic Soc. 63, 69-71 (1980).
7. J. H. Rose and J. L. Opsal, "The inverse Born approximation: An exact procedure for determining flaw shape", Review of Progress in Quantitative NDE, 1, p. 187-195 (1982).
8. J. D. Achenbach, A. N. Norris, L. A. Ahlberg and B. R. Tittmann, "Crack mapping by ray methods", Review of Progress in Quantitative NDE 2A, p. 1097, 1983.
9. L. W. Schmerr, "A new boundary integral equation model for the scattering of elastic waves by cracks", Elastic Wave Scattering and Propagation, V. K. Varadan and V. V. Varadan, Eds., Ann Arbor Science Publishers, 21-31, 1982.
10. T. Joy, P. Ajmera, and W. Strieder, J. Composite Materials, 14, 130 (1980).

BUDGET PLAN (FIRST YEAR)

PROJECT 6. NDE TECHNOLOGY FOR ADVANCED COMPOSITES

TASK 6.2. DETECTION AND CHARACTERIZATION OF DEFECTS
IN COMPOSITES

INVESTIGATORS:

D. Hsu	50.0%
1 Student	

Wages and Salaries	\$ 38,750
Benefits	6,838
Materials and Services	2,000
Travel	1,000
Computer	1,000
Equipment*	8,500
Indirect Costs**	<u>0</u>
Total Expenses	\$ 58,088

*Items requested:

Precision goniometer	\$ 2,500
Polisher	3,600
Optical meter	<u>2,400</u>
	\$ 8,500

**Cost shared by ISU.

PROJECT 7. SYSTEM INTEGRATION, TEST, AND EVALUATION

OVERVIEW:

Essential steps in the reduction to practice of research results are the construction of prototype systems and their test and evaluation. Despite the obvious need for such an activity, the required programs do not seem to have been undertaken with the necessary regularity in the United States; it would appear that our western European and Japanese colleagues are more advanced in this regard. For example, in his preface to the proceeding of a Germany-United States Workshop on new nondestructive testing procedures, sponsored by the NSF and held on August 30-September 3, 1982 in Saarbrücken, Germany, Holler (Director of the Fraunhofer Institute for Nondestructive Testing) observed that (1) "It is obvious, in looking through the program, that many more individuals and organizations are involved in the theoretical area in the country of our guests [U.S.] than in Germany. But it became apparent that we are a bit further ahead in the technical development of new systems and their implementation. Several new systems have already been applied or are ready or nearly ready for implementation:" The tasks in this project are intended to be a step towards the correction of this problem.

The first task is concerned with the development of hardware as needed to implement a recently developed ultrasonic technique for predicting the texture and resulting plastic deformability of metal plates. This is a reduction to practice of ideas developed earlier in the Metallurgy and Ceramics Program of the Office of Basic Energy Sciences, USDOE, and in Air Force and DARPA sponsored programs. The three year program includes phases of hardware construction, demonstration of ability to measure texture, and demonstration of ability to predict plastic deformability. Applications in process control and in the evaluation of incoming materials are envisioned for a variety of industries.

The second task is concerned with the development of a new set of procedures to be used in evaluating the performance of ultrasonic inspection systems. As a baseline, a set of transducers and pulser-receivers will be selected. Following present calibration procedures, the variabilities in the responses from several flaws will be observed.

Modern models for the understanding of ultrasonic wave propagation will then be employed to define the causes of these variabilities. New procedures for calibration which make explicit use of this theoretical understanding will then be developed. The objective will be to define a set of procedures whereby the ability of a system to make absolute measurements, and hence measurements which are completely transferable, can be demonstrated.

REFERENCES:

1. New Procedures in Nondestructive Testing, P. Holler, Ed. (Springer-Verlag, Berlin, 1983).

TASK 7.1. ULTRASONIC MEASUREMENT OF TEXTURE

OBJECTIVE:

The objective of this task is to develop a laboratory breadboard instrument to measure the texture of rolled metal plates.

SCOPE:

The program will be based on the relationship of ultrasonic wave velocities to the preferred orientation of crystallites in a metal plate. During the first year, a breadboard, semi-automatic system for measuring the angular dependence of the ultrasonic wave velocity in the plane of the plate, using couplant free EMAT transducers, will be constructed. In the second year, the system will be used to measure the wave speed anisotropies in a series of plates of different materials and microstructures. The system may also be used in connection with Task 3.1 (Al-Li alloys). The correlation of these results with theoretical predictions, based on independent measurements of the anisotropic elastic constants, will be evaluated. During the third year, the ability to predict anisotropic plastic behavior based on the ultrasonic texture measurements will be studied. The conclusion of the third year, details of the system and its capabilities will be documented for industrial utilization.

BACKGROUND:

The influences of texture on the mechanical properties of metal plates are well known (1,2). One of the most common examples is the ability to be deeply drawn, a property of great importance in aircraft, automotive, and beverage container applications. For example, textures in cubic metals in which $\langle 111 \rangle$ axes are preferentially aligned perpendicular to the plane of the sheet while the $[111]$ planes are randomly oriented in the plane of the sheets as known to exhibit high strengths and R-ratios. Different textures may have poorer values of these mechanical properties and may also exhibit excessive "earing" during drawing, which leads to material wastage. Other important benefits of proper texture control include the achievement of high, through-wall strength in pressure vessels and attainment of tailored magnetic properties in oriented, silicon steel.

It has long been recognized that the elastic moduli are influenced by texture (3,4), and that this could be the basis for ultrasonic texture measurement procedure (5). However, application to the

prediction of control of mechanical properties has been inhibited by difficulty in relating the anisotropy in moduli (which the ultrasonic measures) to the x-ray pole figures (which metallurgists relate to mechanical properties). Recent advances in the modeling of polycrystalline mechanical properties and the general availability of high speed computers have laid the foundations for the necessary link.

The central element of this link is the concept of a crystallite orientation distribution function (CODF) which quantifies the angular variation of grain orientation. The CODF, W , is expanded as a series of generalized legendre functions z ,

$$W(\xi, \psi, \phi) = \sum_{\ell=0}^{\infty} \sum_{m=-\ell}^{\ell} \sum_{n=-\ell}^{\ell} W_{\ell mn} Z_{\ell}(\xi) e^{-im\psi} e^{-in\phi} \quad (1)$$

where ξ, ψ , and ϕ are Euler angles (6,7). The coefficients $W_{\ell mn}$, by which the orthogonal functions $Z_{\ell}(\xi) \exp[-i(m\psi + n\phi)]$ are multiplied, completely define the texture. It is well known that, for cubic crystals, the first four of those coefficients fully define the elastic constants (using such averaging schemes as Voigt or Reuss). Thompson et al. have recently predicted how the coefficients might be deduced from measurements of the guided ultrasonic modes of a plate (9). Since these first four coefficients are also the most important in predicting the plastic anisotropy of cubic metals (10,11), the prospects of a nondestructive test for drawability appear good.

APPROACH:

First Year Effort. During the first year, a laboratory breadboard system will be constructed for the semi-automatic measurement of the velocity of the SHo (fundamental, horizontally polarized shear modes) and So (fundamental, symmetric Lamb mode) of a thin plate. The device is planned to consist of two sets of transducers, one for each guided mode type, driven by a common set of electronics. Each set will contain a single transmitting transducer and a pair of receiving transducers, mounted in a holder which fixes the propagation path lengths. By comparing the arrival times at the two receiver positions, an absolute value for the wave speed will be obtained. Included will be a goniometer which will allow the angular orientation of the probes to be manually indexed in controlled increments.

A desktop computer will also be included and programmed to a) instruct the operator regarding the next goniometer setting, b) read the time delay from a digitally controlled counter, and c) compute the velocity. After collecting a set of data at an appropriate set of angles for both modes, the computer will compute the first four coefficients of the CODF following the procedures outlined in Ref. 9.

Second and Third Year's Efforts. During these two years, the texture measurement system will be evaluated by measurements on an extensive set of samples. Initial efforts, during the second year, will be directed towards verifying that the anisotropic elastic moduli are being correctly inferred from the ultrasonic data. This will be accomplished by first examining the plate material with the EMAT system and then sectioning the plate into smaller specimens whose elastic constants can be determined by other techniques. Primary attention will be given to checking the predictions for Young's modulus, which will be independently determined from measurements of the extensional resonances of bar shaped samples. The possibility of predicting the plate response to deep drawing from the texture data will finally be examined. A variety of papers, which have appeared in the literature suggesting such a possibility, will be reviewed and experimentally evaluated. According to the results, the desktop computer will be programmed so that anisotropic plastic properties are predicted on the basis of the nondestructive measurements.

OUTPUT:

1. An EMAT system for semi-automatically measuring the anisotropic elastic constants of a rolled metal plate.
2. Software routines for predicting the first four coefficients of the CODF expansion.
3. Verification of system operation on a variety of samples.
4. Evaluation of the ability to predict anisotropic plastic properties from this data.
5. Complete documentation of system for industrial utilization.

SENIOR INVESTIGATOR:

R. B. Thompson
Technician

AVAILABLE EQUIPMENT:

1. Wavetek Model 190 Function Generator
2. Matec Model 5100 Gating Modulation
3. Matec Model 515A R. F. Gated Amplifier
4. Panametrics Model 5055 PR used as a Receiver
5. Panametrics Model 5052G Stepless Gate
6. Kron-Mite Model 3202 Variable Pass Band Active Filter
7. Tektronix 465B Oscilloscope
8. Hewlett Packard Time Averaging Counter

EQUIPMENT NEEDED (FIRST YEAR):

Matec Transmitter
 Receiver
 Stepless Gate
 Time Averaging Counter
 Vector Impedance Meter

REFERENCES:

1. M. A. Meyers and K. K. Chawla, Mechanical Metallurgy: Principles and Applications (Prentice Hall, Englewood Cliffs, NJ), 1984.
2. G. E. Dieter, Mechanical Metallurgy, (McGraw-Hill, NY), 1976.
3. Y. C. Liu and G. A. Alers, Trans. Met. Soc. AIME 236, 489 (1966).
4. E. P. Papadakis, Trans. Met. Soc. AIME 236, 1609 (1966).
5. B. R. Tittmann and G. A. Alers, Met. Trans. 3, 1307 (1972).
6. R. J. Roe, J. Appl. Phys. 36, 2024 (1965).
7. H. J. Bunge, Krist. Tech. 3, 431 (1968).
8. C. M. Sayers and D. R. Allen, J. Phys. D 17, 1399 (1984).
9. R. B. Thompson, J. F. Smith and S. S. Lee, "Inference of stress and texture from the angular dependence of ultrasonic plate mode velocities", in, Inprocess Nondestructive Characterization and Process Control, edited by H. N. G. Wadley (American Society for Metals, Metals Park, OH) (in press).
10. G. J. Davies, D. J. Goodwill and J. S. Kallend, Met. Trans. 3, 1627 (1972).
11. R. Sowerby, "Deformation texture in some non-ferrous metals". to be published in the proceedings of the Symposium on Texture of Non-Ferrous Metals held as part of the 1984 Fall TMS-AIME Meeting, Sept. 16-20, 1984, Detroit, MI.

BUDGET PLAN (FIRST YEAR)

PROJECT 7. SYSTEM INTEGRATION, TEST, AND EVALUATION

TASK 7.1. ULTRASONIC MEASUREMENT OF TEXTURE

INVESTIGATORS:

R. B. Thompson	12.5%
Technician	50.0%

Wages and Salaries	\$ 23,694
Benefits	5,923
Materials and Services	4,000
Travel	2,000
Computer	1,000
Equipment*	21,500
Indirect Costs**	<u>0</u>
Total Expenses	\$ 58,117

*Items requested:

Matec Transmitter	\$ 5,000
Receiver	2,000
Stepless gate	1,800
Time averaging counter	4,700
Vector impedance meter	<u>8,000</u>
	\$ 21,500

**Cost shared by ISU.

TASK 7.2. ULTRASONIC STANDARDS

OBJECTIVE:

To improve the ability to intercompare ultrasonic observations made at different laboratories through the development of improved specifications and procedures for ultrasonic calibration.

SCOPE:

This task will begin with an experimental and theoretical assessment of the causes of errors encountered when different laboratories measure and compare the ultrasonic response of various reflectors. Based on the deficiencies identified, new procedures will be developed which make use of reference specimens whose ultrasonic responses are traceable to invariant theoretical values and model based signal processing techniques for the compensation for beam diffraction and material attenuation effects.

BACKGROUND:

Many national and international groups are engaged in the task of standardizing the hardware and procedures involved in ultrasonic testing. The published proceedings of a Symposium on Standards sponsored by NBS, ASTM and ASNT (1) is a good summary of many of these efforts, as they stood in 1977.

Although an ultrasonic test is a highly coupled process, it is clear from the literature that the specification of standards has tended to split into two categories. On one hand, the detailed electrical and physical characteristics of pulser-receivers and transducers are being probed so that standards on search unit-transducer combinations can be established. As McElroy indicated (2), some important operating parameters which must be controlled at this end are:

1. Frequency
2. Effective area of the piezoelectric element
3. Beam geometry, i.e., axial pressure distribution, beam cross-sectional symmetry, and direction
4. Bandwidth and damping factor
5. Conversion efficiency
6. Electrical impedance.

He also pointed out that since requirements for operating parameters vary widely from industry to industry, it is difficult to develop a single standard that will satisfy all inspection needs simultaneously.

Further progress in defining which of these parameters needs to be specified are being made more recently under the auspices of ASTM.

A second important area of standards that has been pursued vigorously is the development of reference (calibration) blocks. These blocks have been used primarily to:

1. establish inspection procedures
2. determine inspection sensitivity levels
3. check equipment performance
4. prove acceptability of components and materials
5. permit repeatability of inspections.

Many tests involving such blocks have utilized peak amplitude of a pulse-echo response of a flat bottom hole as the pertinent quantity to be measured.

However, Burley pointed out (3): "...you cannot reproduce amplitude response curves on a given set of test blocks at different laboratories unless you use the same or equivalent search units and electronic instrumentation." Thus, the specification of the measurement system and the standard reflectors cannot be treated independently. Such effects are clearly described in the recent work of Doctor (4). In studying the relative responses of 3 pulser-receivers and 6 probes (as commonly used in other nuclear industry) to a series of defects (side-drilled holes, notches, saw cuts, thermal fatigue cracks, stress-corrosion cracks) he observed variabilities of 20 to 70%. This variability also was highly dependent on the type of defect being interrogated.

If other parameters are substituted for peak amplitude response such as magnitude of the frequency spectrum or phase response, the inadequacy of the flat bottom hole as a reference target becomes even more evident. For this reason, Tittmann et al. (5) have proposed an alternate calibration standard based on the far-field response of a spherical cavity or inclusion. The advantage of such a target is that the true response is well known, in absolute terms, from theoretical solutions. Furthermore, procedures developed by Thompson and Gray (6) to correct for diffraction and attenuation have demonstrated how this absolute response of the flaw, known as the scattering amplitude can be deduced from experimental observations. Thus,

the key element of a calibration procedure should be the question as to whether a known, invariant theoretical value has been obtained. The errors encountered in attempts to reproduce this number then becomes the basis for the intercomparison of the accuracy, repeatability, and reliability of measurement systems.

APPROACH:

As indicated above, variability in ultrasonic testing arises from a variety of sources. Equipment and transducer differences, material variations and propagation effects all contribute to a variability in the ultrasonic response obtained from a given flaw. The relative importance of these factors depends on the spectral characteristics of the flaw's response. In this project, the relative role of these effects will first be quantified using a variety of pulsed and receivers and transducers. Improved procedures based on the ideas of Tittmann et al. (5) as discussed above, will then be developed.

First Year. In the first year we propose to use a variety of ultrasonic transducer and pulser-receiver combinations and reference specimens containing elementary scatterers such as spherical voids or circular cracks whose responses are known theoretically. Each of the combinations will first be calibrated according to standard procedures and will then be used to obtain the reflectivities of those scatterers relative to the relevant standard reflectors. It is anticipated that different results will be obtained with the different measurement system combinations. In addition, the same data will be analyzed in accordance with the procedures proposed by Tittmann et al. (5), and making use of the measurement model of Thompson and Gray (6). Thus, scattering amplitudes will be derived from the data and compared to the invariant theoretical responses. Errors are again expected, although they are not anticipated to be as great. For each of these types of calibration procedure, the measurement errors will be correlated with the relevant characteristics of the transducers, pulser-receivers, and flaws.

Second and Third years. Based on the expectation that the model based calibration procedures will exhibit substantially lower errors, we anticipate that it will be appropriate to develop a series

of new specifications and protocols for system calibration. These will be based on the idea that the measurement must be made in such a way that an absolute acoustic output is obtained. Included will be the standardization of a) appropriate forms of the measurement model for eliminating diffraction effects and attenuation and b) techniques for determining and deconvolving the transducer output. Close attention will be paid to cooperation and consultation with existing standards bodies so that particularly, an NBS, practical, realizable methodology can be established. Continuing advances in instrumentation and transducers will be monitored and tested, where appropriate, with the proposed specifications.

OUTPUTS:

1. Measurement and interpretation of the relative errors in present and newly proposed calibration procedures.
2. Presuming the latter to be more accurate, specification of standardized procedures for calibration of measurement systems in terms of their ability to reproduce an absolute, theoretically known, response.

INVESTIGATORS:

A. Pate
D. O. Thompson
Student

AVAILABLE EQUIPMENT:

Ultrasonic Pulsers and Receivers
Selection of Transducers
Model Test Samples

EQUIPMENT NEEDED (FIRST YEAR):

None

REFERENCES:

1. Nondestructive Testing Standards-A Review, H. Berger, Ed., ASTM STP 624, Philadelphia, PA, 1977.
2. McElroy, J. T., "Search Unit Standardization", *ibid*, pp. 133-137.
3. Burley, C. E., "Calibration Boocks for Ultrasonic Testing", *ibid*, pp. 146-158.
4. Doctor, S., "Ultrasonic testing equipment standards", Proc. 7th Intl. Conf. on NDE in the Nuclear Industry, Grenoble, France. January 28-February 1, 1985 (to appear).

5. Tittmann, B. R., Thompson, D. O. and R. B. Thompson, "Standards for Quantitative Nondestructive Examination", Ref. 1, pp. 295-311.
6. Thompson, R. B. and T. A. Gray, "A model relating ultrasonic scattering measurements through liquid-solid interfaces to unbounded medium scattering amplitudes", J. Acoust. Soc. Am., 74, 1275-1290 (1983).

BUDGET PLAN (FIRST YEAR)

PROJECT 7. SYSTEM INTEGRATION, TEST, AND EVALUATION

TASK 7.2. ULTRASONIC STANDARDS

INVESTIGATORS:

D. Thompson	12.5%
A. Pate	25.0%
1 Student	

Wages and Salaries	\$ 21,734
Benefits	5,434
Materials and Services	4,000
Travel	2,000
Computer	1,000
Equipment	0
Indirect Costs**	<u>0</u>
Total Expenses	\$ 34,168

*Assumes one graduate assistant salary paid by ERI.

**Cost shared by ISU.

CENTER FOR NDE
ADMINISTRATION

CENTER STAFF:

Computer Programmer	50.0%
Administrative Assistant	50.0%
1 Secretary	
Wages and Salaries*	\$ 39,858
Benefits	9,964
Materials and Services	17,808
Travel	5,000
Computer	0
Equipment	0
Overhead**	<u>34,000</u>
Total Expenses	\$106,630

*Salaries for Director and Deputy Director paid by University (25%-each).

**Overhead applicable to NSF operating grant.

APPENDIX B: RESUMES



JOHN P. BASART

Professor, Electrical Engineering
Dept., Iowa State University

Office: 121 Coover
Ext.: (515)-294-4955

PERSONAL HISTORY:

B.S., 1962, Electrical Engineering, Iowa State University; M.S., 1963, Electrical Engineering, Iowa State University; Ph.D., 1967, Electrical Engineering, Iowa State University.

RESEARCH INTERESTS:

Signal processing revolving around data collected with the Very Large Array (VLA) radio telescope. Data are collected in a two-dimensional spatial frequency domain. Operations on the data to form an image include editing and calibration, a two-dimensional fast Fourier transform, a deconvolution algorithm called CLEAN which removes sidelobes from the synthesized beam, and a self-calibration procedure which reduces phase noise. For large antenna separations and centimeter wavelengths, atmospheric disturbances of the phase can be severe. We are modeling this process using Box-Jenkins time series analysis and placing models in a Kalman filter. The phase data are then filtered.

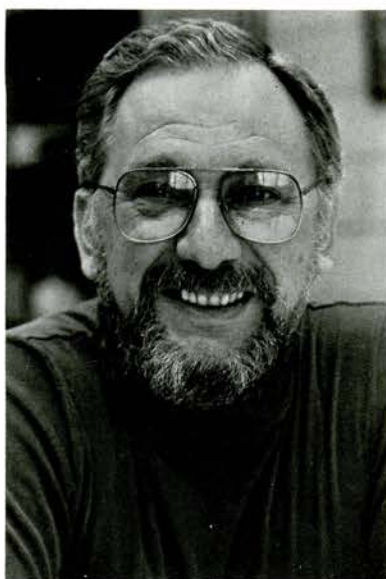
RECENT PUBLICATIONS:

M. D. Andrews, J. P. Basart and R. C. Lamb, "Observations of the radio source G6.6-0.1. Positionally coincident with the W28 SNR", submitted to The Astronomical Journal.

J. O. Burns, J. P. Basart, D. E. DeYoung and D. C. Ghiglia, "Radio jets in classical double radio sources with strong cores", Astrophysical Journal, Vol. 283, pp. 515-528 (1984).

M. D. Andrews and J. P. Basart, "High-resolution radio observations of nonthermal sources in the Rho ophiuchus dark cloud", Astronomical Journal, Vol. 89, pp. 417-420 (1984).

M. D. Andrews, J. P. Basart, R. C. Lamb and R. H. Becker, "High-resolution radio and x-ray observations of the supernova remnant W28", Astrophysical Journal, 266, 684-688 (1983).



OTTO BUCK

Senior Scientist and Section Chief,
Ames Laboratory and Professor of
Materials Science and Engineering,
Iowa State University

Office: 205 Metals Development
Ext.: (515)-294-3930

PERSONAL HISTORY:

Ph.D., 1961, Metal Physics, University of Stuttgart, W. Germany; Principal Scientist, Rockwell International Science Center, 1968-80; Ames Laboratory, 1980-Present; Editorial Board "Journal Nondestructive Evaluation".

RESEARCH INTERESTS:

Mechanical properties, fracture, fatigue and NDE.

RECENT PUBLICATIONS:

W. L. Morris, M. R. James, and O. Buck, "A simple model of stress intensity threshold and crack closure stress", Eng. Fract. Mechanics 18, 871 (1983).

C. V. Owen and O. Buck, "The effect of hydrogen solubility on the internal friction of V-Ti alloys", Scripta Met. 17, 649 (1983).

O. Buck, B. J. Skillings, and L. K. Reed, "Simulation of closure: Effects on crack detection probability and stress distributions", in, Review of Progress in Quantitative NDE 2A, D. O. Thompson and D. E. Chimenti, Eds., Plenum Press, NY, 1983, p. 345.

C. V. Owen, D.-S. Cheong, O. Buck, and T. E. Scott, "Effects of hydrogen on mechanical properties of vanadium-niobium alloys", Met. Trans 15A, 147 (1984).

J.-M. Baik, J. Kameda, and O. Buck, "Small punch test evaluation of intergranular embrittlement of an alloy steel", Scripta Met. 17, 1443 (1983).

R. Ranjan and O. Buck, "On life prediction under stress corrosion conditions below K_{ISCC} ", in, Review of Progress in Quantitative NDE 3B, D. O. Thompson and D. E. Chimenti, Eds., Plenum Press, NY, 1984, p. 1251.



TIMOTHY A. GRAY

Engineer, Applied Nondestructive
Evaluation Program, Ames
Laboratory, Iowa State
University

Office: 231 Applied Sciences
Center
Ext.: (515)-294-7743

PERSONAL HISTORY:

B.A., 1973, University of Wyoming; M.S., 1977, Iowa State University;
Ph.D., 1981, Iowa State University; Associate Engineer, 1981-1984, Ames
Laboratory, Iowa State University; Engineer, 1984-Present, Ames Laboratory,
Iowa State University.

RESEARCH INTERESTS:

Direct and inverse ultrasonic scattering techniques. Modeling of ultrasonic
field-flaw interactions. Practical implementation of new NDE techniques.

RECENT PUBLICATIONS:

R.B. Thompson and T. A. Gray, "A model relating ultrasonic scattering
measurements through liquid-solid interfaces to unbounded medium scattering
amplitudes", J. acoust. Soc. Am. 74(4), 1983.

R. B. Thompson, T. A. Gray, D. K. Hsu, J. H. Rose and D. O. Thompson,
"Forward and inverse ultrasonic scattering measurements in realistic
geometries", in, New Procedures in Non-Destructive Testing, Ed., P.
Holler, 317 (1983).

T. A. Gray and R. B. Thompson, "Ultrasonic detection of cracks in web
geometries", Review of Progress in Quantitative NDE 3A, D. O. Thompson
and D. E. Chimenti, Eds., (Plenum Press, New York, 1984), pp. 47-56.

T. A. Gray and R. B. Thompson, "Ultrasonic sizing of cracks in web geometries",
ibid, pp. 269-276.



DAVID K. HSU

Senior Physicist, Ames
Laboratory, Iowa State
University

Office: 226 Applied Sciences
Center
Ext: (515)-294-2501

PERSONAL HISTORY:

B.S., Physics, 1965, National Taiwan University (Republic of China)
Ph.D., 1971, Wayne State University
Physics Department, Colorado State University, 1971-1984
Visiting Physicist, Ames Laboratory, Iowa State University, 1981-1982

RESEARCH INTERESTS:

Ultrasonic velocity and attenuation in metals; nuclear acoustic resonance;
hydrogen in metals; nondestructive evaluation of flaws by ultrasonic
scattering; acoustic and electrical properties of fiber composites;
magnetic leakage imaging of flaws

RECENT PUBLICATIONS:

R. G. Leisure, T. Kanashiro, P. C. Riedi and D. K. Hsu, "Ultrasonic
attenuation due to zener relaxation in single-crystal palladium hydride",
J. de Physique C9, 419 (1983).

D. K. Hsu, J. H. Rose, R. B. Thompson and D. O. Thompson, "Quantitative
characterization of flaws near a surface using inverse Born approximation",
J. of Nondestructive Evaluation, 3(4), 183-188 (1983).

D. K. Hsu, J. H. Rose and D. O. Thompson, "Reconstruction of inclusions
in solids using ultrasonic Born inversion", J. Appl. Phys. 55(1), 162-168
(1984).

D. K. Hsu, "Measurements of ultrasonic scattering from a high symmetry
fiber composite model", Review of Progress in Quantitative NDE 3B, D.
O. Thompson and D. E. Chimenti, Eds. (Plenum Press, NY), 965-974 (1984).



DAVID JILES

Post-doctoral Fellow, Metallurgy
and Ceramics Ames Laboratory, Iowa
State University

Office: 206 Metals Development
Ext.: (515)-294-8215

PERSONAL HISTORY:

Ph.D., 1979, Solid State Physics, University of Hull, United Kingdom;
Research Fellow, Victoria University, Wellington, New Zealand, 1979-81;
Research Associate, Queen's University, Kingston, Canada, 1981-84; Post-Doctoral
Fellow, Ames Laboratory, Iowa State University, Ames, Iowa, 1984

RESEARCH INTERESTS:

Solid State Physics: Magnetism, elastic and mechanical properties,
electronic properties and band structure, metal physics

RECENT PUBLICATIONS:

D. C. Jiles and D. L. Atherton, "Theory of ferromagnetic hysteresis",
J. Appl. Phys., 55, 2115 (1984).

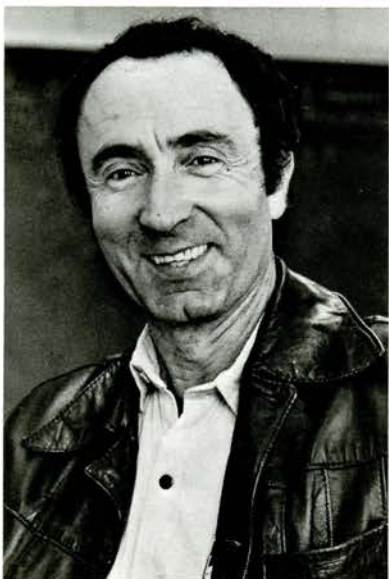
D. C. Jiles and M. P. Staines, "Piezooptic properties of nickel and
platinum", J. Phys. Chem. Sol., 45, 151 (1984).

D. C. Jiles, "Pseudopotential coefficients for the electron band structure
of aluminum and their deformation potentials", Solid State Comms., 51,
327 (1984).

D. C. Jiles and D. L. Atherton, "Theory of the magnetisation process
in ferromagnet and its application to the magnetomechanical effect",
J. Phys. D. (Appl. Phys.), 17, 1265 (1984).

D. C. Jiles, P. W. Gilberd, M. P. Staines and A. Bittar, "Effects of
alloying on the band structure of gold: Piezoreflectance measurements
on some AuCo and AuV alloys", J. Phys. Chem. Sol., 45, 595 (1984).

D. C. Jiles, D. L. Atherton, H. E. Lassen, D. Noble and T. Astle, "A
microcomputer-based system for control of applied uniaxial stress and
magnetic field", Rev. Sci. Instrum. (in press)(1984).



VLADIMIR G. KOGAN

Associate Physicist, Ames Laboratory,
Iowa State University

Office: 223 Applied Sciences
Center

Ext.: (515)-294-2501

Office: 506 Physics

Ext.: (515)-294-8080

PERSONAL HISTORY:

B.A., 1956, Physics and Math., Smolensk, USSR; M.S., 1961, Theoretical Physics, Moscow, USSR; Ph.D., 1977, Theoretical Physics, Technion, Israel Institute of Technology, Haifa, Israel.

RESEARCH INTERESTS:

Superconductivity induced in a normal metal due to proximity with a superconductor. Reconstruction of the scatterer shape from the scattered ultrasound waves.

RECENT PUBLICATIONS:

V. G. Kogan, "Eilenberger equations for moderately dirty superconductors", Phys. Rev. B. (in press) (1984).

V. G. Kogan and J. H. Rose, "Limited aperture effects on ultrasonic image reconstruction", J. of Acoust. Soc. of Amer. (in press) (1984).

R. B. Thompson, V. G. Kogan, J. H. Rose, T. A. Gray and E. F. Lopes, "A comparison of the axial fields of Gaussian and piston transducer radiation after passage through cylindrical surfaces at oblique incidence", Ultrasonic Symposium, IEEE 1983, Atlanta, GA.

V. G. Kogan, "Coherence length of a normal metal in a proximity system", Phys. Rev. B. 88 (1982).

V. G. Kogan and J. R. Clem, "Uniaxial type-II superconductor near the upper critical field", Phys. Rev. B, 2497 (1981).



EDWIN F. LOPES

Asst. Comp. Scientist II, Ames
Laboratory, Iowa State University

Office: 204 Applied Sciences
Center

Ext.: (515)-294-7537

PERSONAL HISTORY:

B.E., Electrical Engineering, 1978, University of Bombay (India);
D.I.I.Sc., Electronics Design, 1980, Indian Institute of Science;
M.S., Electrical Engineering, 1982, Iowa State University; 1983-Present,
Ames Laboratory, Iowa State University.

RESEARCH INTERESTS:

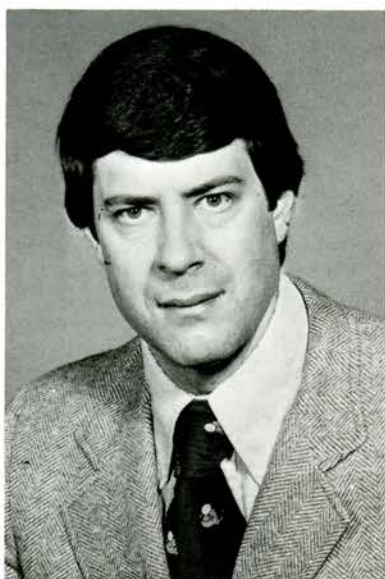
Gaussian ultrasonic beams, development of software for flaw characterization,
synthetic-aperture focussing techniques for ultrasonic testing.

RECENT PUBLICATIONS:

J. H. Rose, T. A. Gray and E. Lopes, "Near surface inspection of
flaws using bulk ultrasonic waves", Review of Progress in Quantitative
NDE 3B, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New
York, 1984), pp. 917-925.

R. B. Thompson, V. G. Kogan, J. H. Rose, T. A. Gray and E. Lopes,
"A comparison of the axial fields of Gaussian and piston transducer
radiation after passage through cylindrical surfaces at oblique incidence",
1983 Ultrasonics Symposium Proceedings, (IEEE, New York, 1983), pp.
905-908.

R. B. Thompson and E. F. Lopes, "The effects of focussing and refraction
on Gaussian ultrasonic beams", J. of Nondestr. Eval. (in press).



JOHN F. MCCLELLAND

Associate Physicist, Ames Laboratory,
Iowa State University

Office: B27 Spedding Hall
Ext.: (515)-294-4922

PERSONAL HISTORY:

B.S., 1965, Dickinson College; Ph.D., 1976, Iowa State University; Physicist 1962-74, National Bureau of Standards; Technical Staff, 1976-77, Honeywell Electro-Optics Center; Ames Laboratory, Post-doctoral Fellow, 1977-79, Iowa State University.

RESEARCH INTERESTS:

Photoacoustic spectroscopy and microscopy (thermal wave) of condensed matter (analytical applications for energy and environmentally related studies, signal generation and detection theory, experimental methods, and instrument development).

RECENT PUBLICATIONS:

W. A. Kamitakahara, H. R. Shanks, J. F. McClelland, U. Buchenan, F. Gompf and L. Pintschovius, "Measurement of phonon densities of states for pure and hydrogenated amorphous silicon", Phys. Rev. Letts. 52, 644 (1984).

H. R. Shanks, W. A. Kamitakahara, J. F. McClelland and C. Carlone, "Phonon density of states of amorphous silicon", J. Noncrystalline Solids 59, 197 (1983).

L. M. Seaverson, J. F. McClelland, G. Burnet, M. K. Iles and J. W. Anderegg, "Investigation of water and hydroxyl groups associated with coal fly ash by thermal desorption and FTIR-PAS", Appl. Spectrosc. (in press).

D. J. Gerson, J. F. McClelland, S. Veysey and R. Markuszewski, "Characterization of coal using FTIR-PAS", Appl. Spectrosc. (in press).

J. F. McClelland, "Photoacoustic spectroscopy", Anal. Chem. 55, 89A (1983).

J. F. McClelland, R. N. Kniseley and J. L. Schmit, "Photoacoustic imaging of compositional variations in $Hg_{1-x}Cd_xTe$ semiconductors", in, Scanned Image Microscopy, E. A. Ash, Ed. (Academic Press, London, 1980), p. 353.



T. J. MCDANIEL

Professor, Aerospace Engineering,
Iowa State University

Office: 358 Town Engineering
Ext.: (515)-294-8004

PERSONAL HISTORY:

B.S., 1962, University of Illinois, Aeronautical and Astronautical Engineering; M.S., 1964, University of Illinois, Aeronautical and Astronautical Engineering; Ph.D., 1968, University of Illinois, Aeronautical and Astronautical Engineering; Summer Employee, 1960-1964, The Boeing Company; Research Engineer, 1967-1973, University of Dayton Research Institute, Dayton OH; Professor Aerospace Engineering and Engineering Research Institute, 1973-1984, Iowa State University, Ames, IA.

RESEARCH INTERESTS:

Finite element analysis of structures; Dynamic response of structures; Fabrication and analysis of composite materials; Testing of composite materials.

RECENT PUBLICATIONS:

T. J. McDaniel and M. J. Carroll, "Dynamics of bi-periodic structures", Journal of Sound and Vibration, Vol. 81(3), pp. 311-335 (1982).

T. J. McDaniel and K. J. Chang, "Dynamics of rotationally periodic large space structures", Journal of Sound and Vibration, Vol. 68(3), pp. 351-368 (1980).

T. J. McDaniel, F. J. Testa and P. V. Babu, "Solution bounds for transient vibration problems", Journal of Applied Mechanics, Vol. 99(1) (1977).

T. J. McDaniel and V. R. Murthy, "Bounds on the dynamic characteristics of rotating beams", AIAA Journal, Vol. 15(3), pp. 439-441 (1977).

T. J. McDaniel and K. B. Eversole, "A combined finite element-transfer matrix structural analysis method", Journal of Sound and Vibration, Vol. 51(2), pp. 157-169 (1977).



ANNA L. MIELNICKA-PATE

Assistant Professor, Dept. of Engineering
Science and Mechanics, Iowa State
University

Office: 204 Engineering Research
Institute
Ext.: (515)-294-6240

PERSONAL HISTORY:

M.S., EE, 1972, Technical University of Warsaw; Ph.D., 1978, Technical University of Krakow (Poland); 1980 Post-doctoral Research Associate, Purdue University; 1981-82 private Acoustic Consultant, San Francisco, CA; 1982-Present, Assistant Professor, Iowa State University.

RESEARCH INTERESTS:

Theoretical and experimental investigations of source radiation. Sound intensity methods. Source and transmission path identification based on statistical signal analysis, particularly using correlation, coherence and cross-spectra functions. Fourier transform and signal processing to investigate systems behavior. Non-contact measuring methods based on acoustic field. Industrial noise control.

RECENT PUBLICATIONS:

Anna L. Mielnicka-Pate, "Finite difference nearfield errors for a baffled vibrating piston", J. Acoust. Soc. Am., 76, (1984).

Anna L. Mielnicka-Pate and J. Adin Mann III, "Effects of reflector on two-microphone sound intensity measurements", 77th Air Pollution Control Association Annual Meeting, San Francisco, CA, 1984.

Anna L. Mielnicka-Pate, "Acoustic intensity measurements in the reflective environment", J. Acoust. Soc. Am., Suppl. 1, 74, (1983).

Anna L. Mielnicka-Pate, Thomas R. Norris and Mark M. Gmerek, "Tonal fan casing noise case history", Proceedings of Noise-Con. 83, Massachusetts Institute of Technology, 293-296 (1983).



DAVID K. REHBEIN

Associate Metallurgist, Ames
Laboratory, Iowa State University

Office: 206 Metals Development
Ext.: (515)-294-8215

PERSONAL HISTORY:

B.S., 1977, M.S., 1979, Iowa State University; Iowa State University,
1979-Present.

RESEARCH INTERESTS:

Fatigue crack growth and crack closure, development of new NDE evaluation techniques.

RECENT PUBLICATIONS:

D. K. Rehbein, J. F. Smith and D. O. Thompson, "Evaluation of interfacial stresses from the amplitude of reflected ultrasonic signals", Symposium on Applications and Development of Nondestructive Evaluation for Use in Materials Processing, ASM (1983).

D. K. Rehbein, B. J. Skillings, J. F. Smith and D. O. Thompson, "Ultrasonic reflection from a stressed interface", J. Nondestructive Evaluation 4, 1, p. 3.

F. A. Schmidt, M. S. Beck, D. K. Rehbein, R. J. Conzemius and O. N. Carlson, "Electrotransport and diffusivity of molybdenum, rhenium, tungsten and zirconium in beta-thorium", J. Electrochemical Society Vol. 131, No. 9, p. 2169 (1984).

D. K. Rehbein, D. O. Thompson, B. J. Skillings and J. F. Smith, "Inference of compressive stresses from clamped interfaces using ultrasonic measurements", Review of Progress in Quantitative NDE 3B, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1984), pp. 1321-1330.

O. Buck, R. B. Thompson and D. K. Rehbein, "Interaction of ultrasonic waves with simulated and real fatigue cracks", Review of Progress in Quantitative NDE 4, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York (to be published in 1985)).



WILLIAM F. RILEY

Professor of Engineering Science
and Mechanics, Iowa State University

Office: 206 Lab of Mechanics
Ext.: (515)-294-2877

PERSONAL HISTORY:

B.S., Mechanical Engineering, Carnegie Institute of Technology, 1951;
M.S., Mechanics, Illinois Institute of Technology, 1958; Mechanical
Engineer, Mesta Machine Company, 1951-1954; Research Engineer, IIT
Research Institute, 1954-1966; Consultant, USAID/NSF in India, Summers
of 1966 and 1970; Professor of Engineering Mechanics, Iowa State
University, 1966-Present.

RESEARCH INTERESTS:

Principal area of research interest is Optical Methods of Stress
Analysis.

RECENT PUBLICATIONS:

"Instrumentation for engineering measurements", with J. W. Dally
and K. G. McConnell, John Wiley & Sons, Inc., New York, 1984.

"Experimental stress analysis", with J. W. Dally, McGraw-Hill Book
Company, New York, 1st edition 1965, 2 edition 1978.

"Mechanics of materials", with A. Higdon, E. H. Ohlsen, W. B. Stiles,
and J. A. Weese, John Wiley & Sons, Inc., 3 edition 1976, SI edition
1978, 4th edition, 1985.

R. L. Marino, Jr. and W. F. Riley, "Optimizing thread-root contours
using photoelastic methods", Experimental Mechanics, Vol. 4, No.
1, pp. 1-10, 1964.

A. A. Read and W. F. Riley, "Initial results of a holographic tomosynthesis
technique for fuel-core inspection", Trans. Am. Nuc. Soc., Suppl.
No. 2 to Vol. 19, pp. 10-11, 1974.

W. F. Riley and C. P. Burger, "Dynamic Photoelastic model studies
to improve structural reliability and testing", Proceedings of the
Sixth Brazilian Congress of Mechanical Engineering, Vol B, Paper
B-21, pp. 221-233, December 1981.



THOMAS R. ROGGE

Professor of Engineering Science
and Mechanics, Iowa State University

Office: 204 Lab of Mechanics
Ext.: (515)-294-2956

PERSONAL HISTORY:

B.S., Mathematics, Iowa State University, 1958; M.S., Mathematics, Iowa State University, 1961; Ph.D., Applied Mathematics, Iowa State University, 1964; Faculty Member, University of Arizona, Mathematics Department, 1964; Summer Positions: Sandia Laboratories, Albuquerque, NM, Aerospace Research Laboratory, Wright Patterson Air Force Base, and NASA George Marshall Space Flight Center (Huntsville).

RESEARCH INTERESTS:

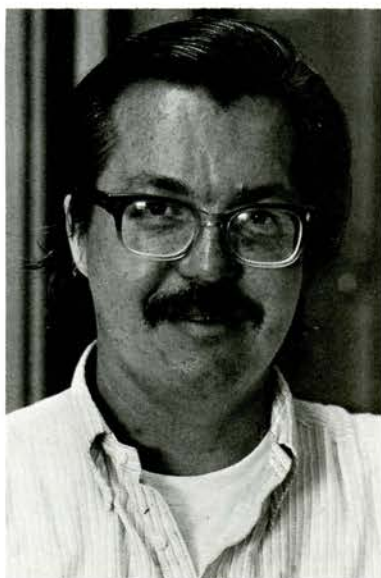
General research interest is in the use of numerical methods to solve problems in continuum mechanics. His main emphasis has been on the use of the finite element method to examine problems of fluid flow in flexible tubes, the determination of stresses, displacements, stress intensity factors in the vicinity of a crack tip, elastic-plastic deformations, and contact problems. A commercial finite element code has been used to study elastic-plastic deformations that occur in contact type problems, and these results were coupled with ultrasonic experiments to allow the measurement of contact stresses using ultrasonic techniques. Other problems that have been studied with the finite element method are the effects on the stress distribution of cracks in welds, the stress distribution in bonds between two materials, and the calculation of stress intensity factors using the J integral.

RECENT PUBLICATIONS:

T. R. Rogge and C. F. Sieck, "The use of non-SAP to compare the von Mises and a modified von Mises yield criteria", Computer and Structures, 17, pp. 5-6 (1983).

E. Rooz, D. F. Young and T. R. Rogge, "A finite-element simulation of pulsatile flow in flexible obstructed tubes", J. Biomech. Eng., 104, p. 119 (1982).

D. F. Young, T. R. Rogge, T. R. Gray and E. Rooz, "indirect evaluation of system parameters for pulsatile flow in flexible tubes", J. Biomech., 14, p. 339 (1981).



JAMES H. ROSE

Associate Physicist, Ames Laboratory,
Iowa State University

Office: 228 Applied Sciences Center
Ext.: (515)-294-7537

PERSONAL HISTORY:

B.A., University of California, Berkeley, CA; M.A. and Ph.D., University of California, San Diego, CA; Phi Beta Kappa; Post-doctoral Fellow, Cornell University, Ithaca, NY; Associate Scientist, University of Michigan, Ann Arbor, MI.

RESEARCH INTEREST:

Nondestructive evaluation; inverse scattering theory; solid state theory; mathematical physics.

RECENT PUBLICATIONS:

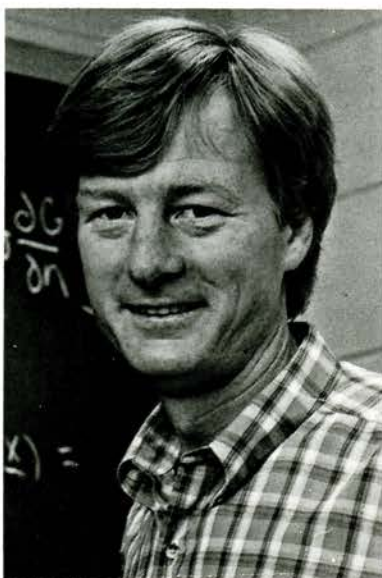
D. K. Hsu, J. H. Rose and D. O. Thompson, "Reconstruction of inclusions in solids using ultrasonic Born inversion", J. of Appl. Physics, 55, 162 (1984).

J. H. Rose, "Exterior reconstruction of a three dimensional scatterer", Wave Motion, 6, 149 (1984).

J. H. Rose, M. Cheney and B. DeFacio, "The connection between time and frequency-domain three-dimensional inverse scattering methods", J. of Mathematical Physics, 25, 2495 (1984).

J. H. Rose, J. P. Vary and J. R. Smith, "Nuclear equation of state from scaling relations for solids", Physical Rev. Lett., 53, 344 (1984).

F. Guinea, J. H. Rose, J. R. Smith and J. Ferrante, "Scaling relations in the equation of state, thermal expansion and melting of metals", Appl. Physics Lett., 44, 53 (1984).



THOMAS J. RUDOLPHI

Associate Professor of Engineering
Science and Mechanics, Iowa
State University

Office: 256 Sweeney
Ext.: (515)-294-7399

PERSONAL HISTORY:

Ph.D., University of Illinois, Theoretical and Applied Mechanics, 1977; Post-doctoral Research Associate, National Research Council, Wright-Patterson Air Force Base; Staff Member, Engineering, Oak Ridge National Laboratory; Faculty, Iowa State University, 1979-Present.

RESEARCH INTERESTS:

Numerical solution methods and appropriate formulation for numerical solutions of problems arising in solid mechanics where the continuum model is applicable. Within this area, his interest has centered around the integral formulation of problems such as the variational or weighted residual approaches and their subsequent numerical solution methods - mainly the finite element and boundary integral methods. He is particularly concerned with accounting for singularities and discontinuities in otherwise continuous fields such as those that occur in fracture mechanics near a sharp crack. He is further interested in combining the boundary element and finite element methods. For problems where most of the domain remains linear and a portion is nonlinear, a combination of methods can exploit the best of each technique. Algorithms to utilize both these methods in solving one problem are undoubtedly useful in a variety of industrial application.

RECENT PUBLICATIONS:

T. Rudolphi, "An implementation of the boundary element method for zoned media with stress discontinuities", Int. J. Num. Meth. Eng., 19, pp. 1-15 (1983).

T. Rudolphi, "A boundary element solution of the edge crack problem", Int. J. of Fracture, 18, pp. 179-190 (1982).

T. Rudolphi, "An integral equation solution for a bounded elastic body containing a crack: Mode I deformation", Int. J. of Fracture, 14, pp. 527-541 (1978).



LESTER W. SCHMERR, JR.

Professor Engineering Science
and Mechanics, Iowa State University

Office: 208 Lab of Mechanics
Ext.: (515)-294-3033
Office: 223 Applied Sciences
Center
Ext.: (515)-294-2501

PERSONAL HISTORY:

B.S., Massachusetts Institute of Technology, Aeronautics & Astronautics, 1965; Ph.D., Illinois Institute of Technology, Mechanics, 1970.

RESEARCH INTERESTS:

Prof. Schmerr has been in the Engineering Science and Mechanics Department at Iowa State University since 1969. His research interests are in the fields of ultrasonic NDE, elastic wave propagation, and the use of boundary element methods. He has developed courses at Iowa State University in NDE at both the undergraduate and graduate level. Currently, he is pursuing the application of artificial intelligence and symbolic processing concepts to NDE and CAD/CAM problems.

RECENT PUBLICATIONS:

L. W. Schmerr, "The scattering of elastic waves by isolated cracks using a new integral equation model", Review of Progress in Quantitative NDE 1, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1982), pp. 511-517.

L. W. Schmerr, "A new boundary integral equation model for the scattering of elastic waves by cracks", Elastic Wave Scattering and Propagation, V. K. Varadan and V. V. Varadan, Eds., Ann Arbor Science, Ann Arbor, MI, pp. 21-31 (1982).

R. B. Thompson, B. J. Skillings, L. W. Zachary, L. W. Schmerr, and O. Buck, "Effects of crack closure on ultrasonic transmission", Review of Progress in Quantitative NDE 2A, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, 1983), pp. 325-344.



JOHN F. SMITH

Senior Metallurgist, Ames Laboratory,
and Professor of Materials Science
and Engineering, Iowa State
University

Office: 122 Metallurgy
Ext.: (515)-294-5083

PERSONAL HISTORY:

B.A., 1948, University of Missouri at Kansas City; Ph.D., 1953, Iowa State University; Iowa State University, 1948-Present.

RESEARCH INTERESTS:

Ultrasonic determination of fastener (bolt) tension; ultrasonic measurement of clamping stresses at interfaces produced during heat-shrink fitting or by Nitinol couplers; independent determination of stress and of texture in rolled sheet and plate over a wide range of thicknesses; ultrasonic determination of elastic parameters, particularly of single crystals and correlation with physical behavior such as superconductivity, phase transformation, etc.

RECENT PUBLICATIONS:

J. F. Smith and J. D. Greiner, "Stress measurement and bolt tensioning by ultrasonic methods", *J. Metals* 32, 34-36 (1980).

D. K. Rehbein, J. F. Smith and D. O. Thompson, "Evaluation of interfacial stresses from the amplitude of reflected ultrasonic signals", in, *Nondestructive Evaluation: Applications to Materials Processing*, ed. by S. Wolf and O. Buck, (American Society for Metals, Metals Park, Ohio, 1984), pp. 155-160.

R. B. Thompson, J. F. Smith and S. S. Lee, "Microstructure-independent acoustoelastic measurement of stress", *Appl. Phys. Lett.* 44, 296-298 (1984).

H. M. Kandil, J. D. Greiner and J. F. Smith, "Single-crystal elastic constants of Yttria-stabilized zirconia in the range 20° to 700°C", *J. Am. Ceram. Soc.* 67, 341-346 (1984).

J. F. Smith, G. A. Alers, P. E. Armstrong and D. T. Eash, "Separation and characterization of stress levels and texture in metal sheet and plate: I. Principles and initial test", *J. Nondest. Eval.*, in process.



R. BRUCE THOMPSON

Senior Scientist, Ames Laboratory,
and Research Professor, Energy
and Minerals Research Institute,
Iowa State University

Office: 216 Applied Sciences
Center
Ext.: (515)-294-7864
Office: 204 Metals Development
Ext.: (515)-294-8252

PERSONAL HISTORY:

Ph.D., Applied Physics, Stanford University, 1970; M.S., Physics, Stanford University, 1965; B.S., Physics, Rice University, 1964; Member of Technical Staff and Group Leader, Rockwell International Science Center, 1970-1980; Ames Laboratory and Iowa State University, 1980-Present.

RESEARCH INTERESTS:

Nondestructive evaluation, ultrasonics, electromagnetics, stress and material property measurements, flaw characterization, modeling inspection reliability.

RECENT PUBLICATIONS:

R. B. Thompson and E. F. Lopes, "The effects of focussing and refraction on Gaussian ultrasonic beams", J. Nondestr. Eval. (in press).

O. Buck and R. B. Thompson, "Ultrasound interaction with partially closed fatigue cracks", in, Proceeding of Fatigue 84, Second International Conference on Fatigue and Fatigue Thresholds, C. J. Beevers, Ed. (Birmingham, in press).

J. D. Achenbach, K.-Y. Hu, A. N. Norris, T. A. Gray and R. B. Thompson, "A model for the ultrasonic scattering from multi-branched cracks", Review of Progress in Quantitative NDE 4, D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York, in press).

R. B. Thompson, J. F. Smith and S. S. Lee, "Microstructure-independent acoustoelastic measurement of stress", Appl. Phys. Lett. 44, 296 (1984).

R. Bruce Thompson, "Quantitative ultrasonics", Trans. ASME, J. Appl. Mechanics, 50, 1191 (1983).

R. B. Thompson and T. A. Gray, "A model relating ultrasonic scattering through liquid-solid interfaces to unbounded medium scattering amplitudes", J. Acoust. Soc. Am. 74, 1279 (1983).



SAMUEL J. WORMLEY

Associate Engr. II, Quantitative
NDE, Ames Laboratory, Iowa State
University

Office: 233 Applied Sciences
Center
Ext.: (515)-294-7743

PERSONAL HISTORY:

NCOIC Maintenance and Signals Analyst. U.S.A.S.A.F.S. Berlin, 1969-1972.
B.S., Mathematics, Iowa State University, 1973. M.E., Electrical
Engineering, Iowa State University, 1975.

RESEARCH INTERESTS:

Flaw reconstruction using theoretical inverse elastic wave scattering
in the long and intermediate wavelength regime. Development of hardware
and software to implement a decision tree for flaw characterization.

RECENT PUBLICATIONS:

D. O. Thompson, S. J. Wormley, James H. Rose and R. B. Thompson,
"Elastic wave scattering from multiple voids (porosity)", Review
of Progress in Quantitative NDE 2A, D. O. Thompson and D. E. Chimenti,
Eds., (Plenum Press, New York, 1983), pp. 867-882.

S. J. Wormley and D. O. Thompson, "Comparison of scattering amplitudes
from various transducers using diffraction and attenuation corrections",
Review of Progress in Quantitative NDE 3A, D. O. Thompson and D.
E. Chimenti, Eds., (Plenum Press, New York, 1984), pp. 323-332.

D. O. Thompson and S. J. Wormley, "Long and intermediate wavelength
flaw reconstruction", Review of Progress in Quantitative NDE 4A,
D. O. Thompson and D. E. Chimenti, Eds., (Plenum Press, New York,
1985) (in press).

APPENDIX C:
SUMMARY MATERIAL
FROM FORMATION MEETING

PROGRAM
FORMATION MEETING
FOR
CENTER FOR NDE
AT
IOWA STATE UNIVERSITY
HYATT DES MOINES, DES MOINES, IA
NOVEMBER 19-20, 1984

Evening, Nov. 19

R. S. Hansen, Chairperson

5:30PM Get Acquainted Hour

6:30PM Opening Comments and
Introduction of Guests

R. S. Hansen
Director, EMRRI
and Ames Laboratory

Guests: W. Robert Parks, President, Iowa State University
Terry Branstad, Governor, State of Iowa
David Swanson, Chair, Iowa High Technology Council

7:15PM Buffet

8:00PM The University/Industry
Cooperative Research Centers
Program

Alex Schwarzkopf
National Science
Foundation

8:45PM Summary of NDE Educational
Advances and Plans at ISU

H. J. Weiss
Head, Dept. of
Engineering Science
and Mechanics

9:00PM Overview of NDE Research at
ISU and the Ames Laboratory

R. Bruce Thompson
Professor, Engineering
Science and Mechanics,
and Senior Scientist,
Ames Laboratory

10:00PM Adjourn

Morning, Nov. 20

W. Riley, Chairperson

8:00AM Discussion of Draft
Prospectus

D. O. Thompson
Professor, Engineering
Science and Mechanics,
and Program Director,
Applied NDE, Ames
Laboratory

8:30AM Review of Proposed Research
Program

Project

Project Spokespersons

1. Model Development and Signal Processing
2. NDE System Design and Component
Inspectability
3. NDE for Material Properties
4. NDE Technology for Advanced Composites
5. NDE of Ceramics and Coatings
6. System Integration, Test, and Evaluation
7. New NDE Techniques

L. W. Schmerr
T. A. Gray

J. Smith
D. K. Hsu
J. McClelland
D. O. Thompson
C. Burger

10:00AM Break

10:15AM Working Group Discussions

12:15AM Lunch

1:15PM Summary of Discussions and
Next Steps

W. F. Riley
Distinguished Professor,
Engineering Science
and Mechanics

2:30PM Adjourn

CENTER FOR NDE

PRELIMINARY SUMMARY OF COMMENTS RECEIVED AT THE FORMATION MEETING IN DES MOINES, IA NOV. 19-20, 1984

1. A strong majority of industrial representatives present agreed with the concept of the Center as described in the draft Prospectus, i.e., a strong emphasis on interdisciplinary NDE research in industrially relevant topics that will serve as an important vehicle in the education of NDE engineers pursuing a disciplinary degree with an NDE option. No change in our basic model and concept for the Center is anticipated.

2. There was interest in all the research projects presented with a distribution of interest about as expected. The research program that will be included in the Final Prospectus will be constructed to reflect this distribution. Please bear in mind that the research projects presented in the Draft Prospectus were developed in response to problem inputs from industrial members; the projects given do not therefore cover all the known NDE problems. If you did not respond to our prescreening inquiry regarding NDE interests, and if you have interests not covered in the project plan, please provide us with the information. We will do our best to include it in our Final Prospectus within constraints provided by Center size, equipment, and skill base. Project make-up can always be changed by the Industrial Advisory Board so long as the changes are consistent with the goals of the Center and the University.

At least four additional items will be provided in the presentation of the Research Program in the Final Prospectus. These are:

a) Summaries of technical work being performed under other programs (AF, DOE, Navy, others) will be given.

b) Specific comments relating proposed Center-sponsored research to research in other programs will also be given as needed for clarification. (For example, the detection and characterization of porosity in composites is a problem of industrial interest. Since the work is underway under AF funding, it was not specifically included in the draft Prospectus since it is available to potential Center sponsors in any case. However, a topic is included in the Composites project that needs to be solved in order to make the porosity results more useful. This topic is the need to clearly identify signals in a defect-free composite which tend to confuse porosity detection).

c) The flow of technology from basic to applied to testbed (integration, test, and evaluation) will be more clearly demonstrated in the project structure in the final Prospectus.

d) A listing of research equipment available for Center research will be given. This will not be a complete listing of equipment available at both ISU and the Ames Laboratory for such a list would be very extensive; rather, the list will be related to research projects given. As stated in the Draft Prospectus (p. 25), much of this equipment is owned by the DOE and the DOD and is available for use in the Center on a non-interfering basis. Discussions are underway with ISU officials to identify alternate ways to procure specific major items. It is planned to spend no more than 20% of Center income on research equipment, a figure that is accepted by various federal agencies as reasonable for equipment maintenance and up-dating.

3. A significant majority of those present favored the inclusion of the Exchange Program (p. 14, Draft Prospectus) and attendance at the Annual Research Conference (p. 15, Draft Prospectus) in the final Prospectus. Most of those who commented on the Exchange Program favored the student cooperative activity and short term visits for Sponsors' representatives (4 week) at the Center. These will be included in the final Prospectus; whether or not a given sponsor wishes to take part in these activities is the sponsor's option.

4. The general consensus showed mixed interest in the Information Dissemination item (p. 14, Draft Prospectus). Essentially all industrial visitors wanted preprints, reprints, reports, etc. as a matter of course. A majority of those present felt, however, that Center funds should be used for technology and student advances and should not be spent on special items such as development of short courses, library services, video training films, etc. The special items will be deleted from the final Prospectus; however, the option remains that any specific sponsor(s) may initiate a specific item through the Center at the individual sponsor's cost.

5. The financial and staffing plans (Table II and III in draft) will be modified to show a ceiling membership of 25-30 companies. This number represented the consensus of industry desires. The tables, as shown in the Draft Prospectus, contain possible income for the Center from other sources (not identified in the Tables) that seems to have confused their interpretation.

6. There were differences in opinions in the amount of detail needed in a patent policy for the Center. The one included in the Draft Prospectus (paragraph 8, Appendix C) is one recommended by NSF and approved by ISU. It was suggested by several that the distribution of any royalties also needs to be stated in the policy. Negotiations are currently underway with ISU to extend the patent policy given in the Draft Prospectus.

7. By and large, the publication policy described in the Draft Prospectus seems to be satisfactory to potential Industrial sponsors (paragraph 7, Appendix C). Please bear in mind that publication is the life-blood of faculty involvement in research; publication of NDE thesis work is also the entry into professionalism for NDE students. The policy as written in no way compromises the benefits that a sponsor gets from the Center; i.e., early contact with students, personalized discussion of research advances with faculty and students, time delay in publication at sponsor's request, no publication if patents are sought by IAB. No change in this policy is anticipated.

8. There appeared to be some concern that the Center would develop primarily as an "ultrasonics" Center. While ISU and the Ames Laboratory are proud of their strengths in ultrasonics, it has been repeatedly stated that the Center will be developed as a full-coverage NDE Center. On p. 24 of the Draft Prospectus it is stated that new research positions will be filled with "world class" people in other technologies such as radiography (μ -focus, real-time image processing, CT, etc.), electro-magnetic techniques, etc. The two additional positions in the College of Engineering noted in the cover letter will also be utilized to

expand the scope. As stated in the meeting and indicated by the resumes in Appendix D, there are also a number of leaders already at ISU and the Ames Laboratory in various disciplines who wish to be involved. These include leaders in optics, NMR, lasers, magnetic measurements, etc. Please be assured that the development plan for the Center is focussed upon a full-coverage Center. It is our plan to make other areas as strong as the ultrasonics.

memorandum

DATE: June 7, 1984

REPLY TO
ATTN OF: Donald Senich, Division Director/ISTISUBJECT: NSF/DOD Cooperation to Enhance Industry-University Interactions-
Meeting with DOD IR&D Policy Council

TO: The File

On Thursday, May 24, 1984 at 2:30 p.m. I gave a short presentation to the DOD IR&D Policy Council on ISTI Industry/ University Cooperative Research programs. The purpose of the presentation was to obtain the Councils' concurrence in the concept of including ISTI cooperative research programs in DOD guidelines for IR&D funding.

Attending the meeting were the following individuals:

DOD

Richard DeLauer, Undersecretary for RDT&E
Edith Martin, Deputy Undersecretary for RDT&E
Assistant Secretaries from the Services
Leo Young, Director for Research and Laboratory Management
Representative from DOD General Counsel

NSF

Richard J. Green, Assistant Director, STIA
Peter Wilkniss, Deputy Assistant Director, STIA
Donald Senich, Division Director, ISTI
Thomas Ryan, Program Specialist, ISTI

The presentation focused on the Industry/University Cooperative Research Projects program and the Industry/University Cooperative Research Centers. During the presentation DOD personnel asked many questions concerning the review procedures and costing practices for the I/U programs. Secretary DeLauer was especially interested in the "cost model" of the projects and the distribution between direct costs and overhead burden. This matter is being looked into and data is being compiled to send over to DOD.

The IR&D Policy Council approved the automatic qualification of NSF Industry/University Cooperative Research programs for IR&D negotiations.

Attached is the NSF proposal to DOD and the DOD guidelines for Industry-University interactions.

Attachments

USE OF NSF INDUSTRY/UNIVERSITY COOPERATIVE RESEARCH PROGRAMS IN
DOD INDUSTRY/UNIVERSITY INTERACTION EVALUATION

Both the NSF and DoD have approaches to foster industry/university interaction in research. One mechanism used by DoD is through incentives incorporated into the negotiated IR&D ceilings of companies with Defense contracts. NSF Division of Industrial Science and Technological Innovation has two programs that foster industry/university interaction in research. The Industry/University Cooperative Research Projects program funds projects that perform collaborative research by university and industry researchers. In this program, NSF funds the university and a portion of the company's research activities for the project. The Industry/University Cooperative Research Centers program initiates large university research programs through confunding with a group of companies. NSF provides "seed funds" and then phases out within a five year period.

Both the DoD and NSF programs can become mutually supporting. Since the NSF Industry/University Cooperative Research Projects require companies to perform collaborative research tasks in conjunction with the university, company funds used for the support of such research activities would meet DoD guidelines for joint research efforts. These research projects should be high calibre since they will have been peer reviewed and approved by NSF.

An Industry/University Cooperative Research Center requires a number of companies to pay a fee to support a large university research program along with NSF. The companies become members of an industry advisory committee for the center, recommending the research projects to be pursued by the university researchers.

Proposal to DoD:

1. NSF requests that programs resulting from a company's participation in NSF Industry/University Cooperative Research Projects automatically be considered part of the company's DoD Industry/University Interaction.
2. NSF requests that companies participating in both DoD IR&D advance agreements and in NSF Industry-University Centers be allowed to report funds used for memberships in NSF Centers as well as funds used to support joint research activities in demonstrating their university interaction for the purpose of the DoD incentive.

Impact of Proposal:

- Leverages company funds with university and NSF monies. Enhanced funding allows for expanded research programs and increased graduate student enrollments with concomitant increase in research results and graduate degree production.
- More companies willing to invest in broader generic science of university-based projects if it is known that the cost is IR&D acceptable.
- NSF peer review system assures DoD of the quality of company sponsored research.

DOD SPECIAL INTEREST ITEMS**DRAFT**I. INDUSTRY-UNIVERSITY INTERACTIONS1. PURPOSE

DoD is encouraging increased interactions between DoD contractors and universities, both as a means of strengthening the technology base from which industry draws and for increasing the rate of technology transition from the academic community to industry. The activities desired are those that strengthen the research capabilities of the universities in science and engineering, contribute to the development of high quality science and engineering graduates, and promote transition of research results into new applications. In order to evaluate the extent of interactions between DoD contractors and universities, contractors are asked to submit information describing their activities in the areas of science and engineering.

2. GUIDELINES

- a. A separate submittal should be provided to the IR&D Manager of the Military Department assigned lead responsibility for the contractor's technical evaluation. The submittal should describe the past year's university activities. Individual project financial summaries for this Special Interest Item (DoD Guidelines, B-2.f) are not required.
- b. The submittal is to be provided with the mini-plan.
- c. The factors listed in Section 4 will provide insight as to the scope and effectiveness of industry-university interaction. Please indicate the extent and nature of activities.

3. DOCUMENT SUBMITTAL

- a. A suggested format for a financial summary sheet is shown in Section 5. This is to be done for corporate level university interactions and for all divisions which negotiate IR&D ceilings. (For divisions which negotiate B&P only, this submittal is not required.)
- b. Following each financial summary sheet (Section 5), the activities that have been listed should be described. A brief overview of each activity is all that is required. A division's submittal should be no more than 5 pages.

4. ACTIVITIES THAT MAY BE CONSIDERED IN PREPARING THE INDUSTRY/UNIVERSITY INTERACTION SUBMITTAL

University subcontracts for R&D. Provide program overview and funding.

Research grants and joint research programs. Provide program overview and funding. (NSF Cooperative Research Projects and Cooperative Research Centers qualify.)

Faculty Consultants. This involves the use of university engineering and science faculty by a company. Provide brief description of involvement, number of faculty, and funding.

Summer employment (faculty and students). Provide program overview, number of students and funding. Consider only university science and engineering students.

Co-op Educational Employment. Provide program overview, number of science and engineering students involved and funding.

Other. Activities that could be listed in this category include (but are not limited to) the following:

- University subcontracts for university services or facilities. Provide program overview and funding.
- Support of scholarships, fellowships and endowed chairs. Consider only scholarships used in the areas of science and engineering. Provide the number of funding.
- Employee education (on and off-site), seminars and panels. Provide a brief description of program, number of employees involved and funding.
- Facilities use. Use of company equipment by university researchers. Provide a brief program description and cost incurred (if possible).

5. SUGGESTED FINANCIAL SUMMARY FORMAT

INDUSTRY-UNIVERSITY INTERACTIONS/SCIENCE & ENGINEERING	DATE
COMPANY NAME	FISCAL YEAR
	FROM TO

<u>PRIMARY ACTIVITIES</u>	UNITS
	(\$, no. of people)

UNIVERSITY SUBCONTRACTS FOR R&D

RESEARCH GRANTS AND JOINT RESEARCH PROGRAMS

FACULTY CONSULTANTS (Science and Engineering)

SUMMER EMPLOYMENT (Science and Engineering)

CO-OP EDUCATIONAL EMPLOYMENT (Science & Engineering)

OTHER ACTIVITIES

TOTAL SALES BASE USED IN NEGOTIATIONS

PRIOR YEAR IR&D NEGOTIATED CEILING

II. WEAPON SYSTEMS READINESS AND SUPPORT

1. PURPOSE

The DoD has undertaken a series of major initiatives to improve the acquisition process. As an integral part of this program the DoD has identified improvements in support and readiness as major objectives to be applied to both the weapon system and support technology areas. Improvements are needed in inherent weapon system reliability and maintainability and other support characteristics, test and support equipment, training equipment, manuals, and other logistic elements external to the weapon, and industrial productivity in the logistics and support areas. A few specific areas requiring R&D to develop the technology needed to realize their potentials are: automatic diagnostics, high mission critical reliabilities, low cost maintenance training devices, long-life materials and components, automatic or electronic documentation production and distribution, maintenance free subsystems, two level maintenance systems, logistics control, and managerial systems. A number of emerging technologies (VHSIC circuitry, automated software development techniques) offer great promise, if properly channeled, for improving system readiness and reducing support costs.

2. GUIDELINES

- a. The Special Interest Item financial summary table described in paragraph B.2.f of the DoD Guidelines for Contractor Presentation of IR&D Information is not required for this Special Interest Item. For Weapon Systems Readiness and Support include additional category designations in column 4 of the Table of Contents/Financial Summary (See Attachment 3). To qualify for such additional designation projects should conform to the following definitions of categories I and II:
- b. Category I Projects: Projects where an objective is to improve Weapon Support or Logistics but this is not the only objective of the project and may or may not be a principal objective.

These projects will either be front-end design for a new technology subsystem, upgrading performance over existing subsystems, or a technology effort that will lead to a new front-end design. The evaluation of these projects will be based on whether creative effort has been applied to making the new design or technology inherently more supportable by technology application to improve reliability and maintainability characteristics and/or by applying support technology to meet or reduce potential support requirements. In some cases, new support approaches for such functions as diagnosis and repair must be created to go along with the technology. In others, technology will permit a major reduction in external support equipment requirements.

- c. Category II Projects: Projects where the principal objective is clearly in the Weapons Support and Logistics area and its successful completion is the major purpose of the project.

These projects focus on technology or front-end design to develop advances in weapon support elements of systems or in logistic systems that support more than one weapon. A range of technology elements is shown below for guidance but is by no means restrictive. In the case where new support technology projects are developed to match requirements of improved performance, for example, new diagnostic approaches to match composites used in components or subsystems, there is a choice whether these are shown as integral tasks of a category I project or separately as category II projects. The company should be free to make this judgement and structure the brochure accordingly. If separated, they should be cross referenced.

- d. Possible Technology Areas for Weapons Systems Readiness and Support Projects include:

Reliability technology
Maintainability technology
Diagnostics technology
Automatic Test Equipment
Logistic training
Maintenance and Overhaul Aids
Metrology for fielded weapon systems
Weapon support equipment
Automated Spare Parts Manufacture
Materiel transportation
Fuels and munitions technology
Logistics Facilities
Logistics communication

- e. Thus a development project for automatic test equipment might be shown in the Summary Table (Described in Attachment 3 and paragraph B.2.c of the DoD Guidelines for Contractor Presentation of IR&D Information) as:

<u>Proj. No.</u>	<u>Proj. Title</u>	<u>Tech. Plan Page</u>	<u>Category</u>	<u>COSATI Code</u>	<u>Prior Year Proposed (\$K)</u>	<u>Prior Year Actual (\$K)</u>	<u>Current Year Proposed (\$K)</u>
R85	Automatic Test Equip.	88	D/II	0901	XXX	XXX	XXX

- f. Weapon Systems Readiness and Support Summary: A short (no longer than five pages) summary should be included in the technical plan which highlights the major projects and technology thrusts which are addressing the improved readiness and support objectives. This will be an overview which conveys by example the extent of corporate commitment to identification and

resolution of key problems and to take advantage of technology opportunity. Where appropriate, the summary could provide company perspective on the balance of the program in terms of areas where opportunity exists versus where it is feasible to address the problems. A suggested categorization of special interest items for the purpose of organizing a summary would be as follows. This would supplement the project by project descriptions in the plan where improved readiness and support objectives would be described where appropriate for each program.

- i. Front End Design and Demonstration Projects - for which reliability and maintenance (R&M) advance over current levels is an integral objective. This may be for weapons, subsystems, elements of subsystems and may be either in conjunction with a performance advance or independent. Such objectives as improved operating reliability, improved storage reliability, reduction of false removals (and alarms), reduction of maintenance times and skill levels could be discussed - quantitatively as appropriate.
- ii. R&M Technology Projects - which would lead to advances which could be applied to future systems and their repair and maintenance. These would include among others: devices, materials, testability approaches, packaging, design processes, diagnostic and architecture, repair technology and methods.
- iii. Support Systems Design and Demonstration Projects - which develop more effective, reliable, less costly test equipment, training, technical information and other support systems. This also includes support systems needed for new technologies in the prime systems including repair methods and procedures.
- iv. Support Systems Technology Projects - which would allow substantial advances in next generation support systems.
- v. Logistic Systems Technology and Demonstrations - which would result in substantial advance in performance of generic logistics functions, e.g., materials handling, distribution, storage, provisioning, management.
- vi. Design and Manufacturing Techniques for R&M and Support - which includes advances in CAE/CAD/CAM to incorporate and simulate R&M in design and would generate logistic data more effectively.

ATTENDEES

CENTER FOR NDE MEETING
HYATT DES MOINES, DES MOINES, IA
NOVEMBER 19-20, 1984

George Baitinger
Fisher Controls Intl., Inc.
205 S. Center
Marshalltown, IA 50158

John P. Basart
Dept. of Electrical Eng.
121 Coover
Iowa State University
Ames, IA 50011
(515)-294-4955

Jim Berry
Aerojet Strategic Propulsion
Company
P.O. Box 15699C
Sacramento, CA 95813
(916)-355-5105

A. R. Bhagat
Wendel Technical Center
P.O. Box 832
Niagara Falls, NY 14302

Marty E. Blubaugh
600 E. Court Ave.
Iowa Development Commission
Des Moines, IA 50322

Ken Bowen
National Water Lift Co.
Control Systems
2220 Palmer Avenue
Kalamazoo, MI 49001
(616)-384-3871

John R. Boase
National Water Lift Co.
2220 Palmer Avenue
Kalamazoo, MI 49001

David R. Boylan
Engineering Administration
104 Marston
Iowa State University
Ames, IA 50011
(515)-294-5933

The Honorable Terry Branstad
Governor of Iowa
Iowa State Capital
Des Moines, IA 50319

Mary Hibbs Brenner
Honeywell, Inc.
10701 Lyndale Avenue S.
Bloomington, MN 55420
(612)-887-6466

Otto Buck
205 Metals Development
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-3930

Ed Bujewski
Bourns, Inc.
300 Airport Road
Ames, IA 50010
(515)-232-3700

Bernard Droney
Bethlehem Steel Corp.
Homer Research Laboratory
Bethlehem, PA 18016
(215)-694-7681

Ronald F. Caster
The Marquardt Company
16555 Saticoy Street
Van Nuys, CA 91409
(213)-989-6606

R. F. Chance
Grumman Aerospace
Mail Stop A01-10
Bethpage, NY 11714
(516)-575-7550

F. H. Chang
General Dynamics Corporation
(MZ 5984)
P.O. Box 748
Fort Worth, TX 76101
(817)-777-3780

W. G. Clark, Jr.
Westinghouse R&D
1310 Beulah Road
Pittsburgh, PA 15235
(412)-256-1160/1099

Michael C. Collins
Allied Bendix Aerospace
Bendix Kansas City Div.
P.O. Box 1159
Kansas City, MO 64141
(816)-997-4829

Roger C. Eckart
Sundstrand Corporation
4747 Harrison Avenue
Rockford, IL 61125

Donald Eitzen
Sound A147
National Bureau of Standards
Gaithersburg, MD 20899
(301)-921-3646

John D. Fenton
LTV Vought M/S 6-16
P.O. Box 225907
Dallas, TX 75265
(214)-266-3075

Douglas K. Finnemore
120 Office and Laboratory
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-4037

David Fischer
Martin Marietta Aerospace
P.O. Box 29304
Dept. 3770
New Orleans, LA 70189
(504)-255-3795

David Foley
Magnaflux Corporation
7300 W. Lawrence Ave.
Chicago, IL 60656
1-(800)-323-0708

Mark Forte
AFALC/PTEM
Wright-Patterson AFB
OHIO 45433
(513)-255-3408

Christopher Fortunko
Aerojet Ordnance
2521 Michele Drive
Tustin, CA 92680
(714)-730-6004 x228

Kenneth Fowler
Panametrics, Inc.
221 Crescent Street
Waltham, MA 02154
(617)-899-2719

William Friedman
The Standard Oil Company
(OHIO)
4440 Warrensville Center Rd.
Cleveland, OH 44128
(216)-581-5265

Dale Galliant
John Deere Tech. Center
3300 River Drive
Moline, IL 61265
(309)-757-5516

Gary Gathman
Parker-Hannifin
18321 Jamboree Blvd.
Irvine, CA 92715
(714)-833-3000 x2387

David A. Geiger
Rockwell International Corp.
P.O. Box 51308
Tulsa, OK 74151

Ray George
Albuquerque Operations
Office
P.O. Box 5400
Albuquerque, NM 87122

Bob Gough
Sundstrand A.T.G.
4747 Harrison Ave.
Rockford, IL 61125

Timothy A. Gray
231 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-7743

H. Handlogten
Sundstrand ATG
P.O. Box 7002
4747 Harrison Ave.
Rockford, IL 61125

Robert S. Hansen
109 Office and Laboratory
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-2770

John A. Harris (Jack), Jr.
Pratt & Whitney (EDFO)
MS 707-22
P.O. Box 2691
West Palm Beach, FL 33402
(305)-840-3282

J. C. Herr
General Dynamics Corporation
Fort Worth Division
P.O. Box 748
Fort Worth, TX 76101
(817)-777-6507

Thomas R. Higgs
Northrop Corporation
A/C Div. 7621/96
One Northrop Avenue
Hawthorne, CA 90250
(213)-416-2810

Steven J. Hooper
352 Town Engineering
Iowa State University
Ames, IA 50011
(515)-294-8922

Robert W. Howe
Standard Oil Co. (INDIANA)
P.O. Box 400, MS B-8
Naperville, IL 60566
(312)-420-5798

David K. Hsu
226 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-2501

David Jiles
206 Metals Development
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-8215

Gilbert E. Joly
General Electric Co.
1 River Road, 28-450
Schenectady, NY 12345
(518)-385-7572

Vladimir Kogan
223 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-2501

Bob Kraus
Eastman Kodak Company
Kodak Park
ATO, Bldg. 35
Rochester, NY 14650

Robert J. Krotz
Alumni Suite-MU
Iowa State University
Ames, IA 50011
(515)-294-4607

Robert J. Lauer
Allied/Bendix Aerospace
1000 Wilson Blvd.
Arlington, VA 22209
(703)-276-2287

Wilson Leeming
Sundstrand Corporation
4747 Harrison Avenue
Rockford, IL 61125
(815)-226-6789

Ron Lindabury
Physical Acoustics Corporation
42868 Lombardy Drive
Canton, MI 48187
(313)-451-1057

Lee A. Linderkamp
Koehring Cranes & Excavators
106 12th St., SE
Waverly, IA 50677
(319)-352-3920

John F. McClelland
B27 Spedding Hall
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-4922

T. J. McDaniel
358 Town Engineering
Iowa State University
Ames, IA 50011
(515)-294-8004

Lou McDougall
Sundstrand, Inc.
2800 E. 13th St.
Ames, IA 50010

John E. Mitchell
Research Dept. TC-A
Caterpillar Tractor Co.
100 NE Adams
Peoria, IL 61629
(309)-578-6203

Roger A. Morris
Los Alamos Natl. Lab.
Group WX-3, MS-C914
Los Alamos, NM 87545
(505)-667-6216

Richard A. Morton
Alumni Suite-MU
Iowa State University
Ames, IA 50011
(515)-294-4607

Steven P. Neal
229 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-7537

Anton J. Netusil
N247C Quadrangle
Iowa State University
Ames, IA 50011
(515)-294-6216

Jim W. Norbury
The Boeing Commercial
Airplane Company
P.O. Box 3707
Seattle, WA 98124-2207

Emmanuel Papadakis
Ford Motor Company
Manufacturing Development Ctr.
24500 Glendale Avenue
Detroit, MI 48239
(313)-592-2060

W. Robert Parks
117 Beardshear
Iowa State University
Ames, IA 50011
(515)-294-2042

George Pherigo
J.A. Jones Appl. Res.
EPRI NDE Center
1300 Harris Blvd.
Charlotte, NC 28215
(704)-597-6131

J. A. Platz
Rockwell International
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, CA 91340
(818)-710-3880

David K. Rehbein
206 Metals Development
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-8215

William F. Riley
206 Lab of Mechanics
Iowa State University
Ames, IA 50011
(515)-294-2877

Neal F. Rinehart
Fisher Controls Company
P.O. Box 11
Marshalltown, IA 50158

Thomas R. Rogge
204 Lab of Mechanics
Iowa State University
Ames, IA 50011
(515)-294-2956

James H. Rose
228 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-7537

Thomas J. Rudolph
256 Sweeney
Iowa State University
Ames, IA 50011
(515)-294-7399

Ward Rummel
Martin Marietta Aerospace
P.O. Box 179, MS0626
Denver, CO 80201
(303)-977-4403

Steve Russell
Dept. of Elec. Eng.
333 Coover
Iowa State University
Ames, IA 50011
(515)-294-1273

Edward Sampson
Aerojet Ordnance Co.
2521 Michelle Drive
Tustin, CA 92680

Paul Sasa
Rockwell International
P.O. Box 464, Bldg. 777B
Golden, CO 80302
(303)-497-2264

Lester W. Schmerr, Jr.
223 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-2501

Joel A. Segel
Aerojet Tech. System Co.
P.O. Box 13400
Sacramento, CA 95813
(916)-355-5639

William W. Shurtleff
Division 7552
Sandia National Labs.
Albuquerque, NM 87185
(505)-844-3500

Alphonso C. Smith
NASA-Langley Research
Center, M/S 234
Hampton, VA 23665
(804)-865-3036

John F. Smith
122 Metallurgy
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-5083

Samuel G. Snow
Martin Marietta
Energy Systems, Inc.
Oak Ridge Y-12 Plant
P.O. Box Y
Oak Ridge, TN 37831
(615)-574-0872

D. H. Stone
Association of American
Railroads
3140 S. Federal St.
Chicago, IL 60616
(312)-567-3580

David H. Swanson
205 Engineering Annex
Iowa State University
Ames, IA 50011
(515)-294-3420

Art Thompson
General Electric Co.-AEBG
1 Newmann Way
Mail Drop G-8
Cincinnati, OH 45215
(513)-243-5208

D. O. Thompson
225 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-7803

R. Bruce Thompson
216 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-7864

James R. (Russ) Tinker
McDonnell Douglas Corporation
Dept. 852C, Bldg. 220
P.O. Box 516
St. Louis, MO 63166
(314)-232-2551

Ray P. Townsend
Townsend Engineering Co.
2425 Hubbell
Des Moines, IA 50317
(515)-265-8181

Y. M. Tsai
211 Lab of Mechanics
Iowa State University
Ames, IA 50011
(515)-294-3124

Janet C. Wade
Garrett Turbine Engine Company
P.O. Box 5217
MS 93-393/503-4Y
Phoenix, AZ 85010
(602)-231-2911

Allen E. Wehrmeister
Babcock & Wilcox Co.
R&D Division
P.O. Box 239
Lynchburg, VA 24505

Harry J. Weiss
214A ERI Building
Iowa State University
Ames, IA 50011
(515)-294-6240

Kumar Wickramasinghe
IBM Corporation
T.J. Watson Res. Ctr.
P.O. Box 218
Yorktown Heights, NY 10598
(914)-945-3794

Daniel E. Williams
119 Office and Laboratory
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-2635

George Williams
Hon Industries
414 E. 3rd Street
Muscatine, IA 52761
(319)-264-7308

Richard S. Williams
United Technologies
Research Center
MS 86
East Hartford, CT 06108
(213)-727-7434

Alec R. Willis
Acceptance Technology-Div. 8444
Sandia National Laboratories
Livermore, CA 94550
(415)-422-2641

Ted L. Winterrowd
Cummins Engine Company, Inc.
Mail Code 50183
P. O. Box 3005
Columbus, IN 47202-3005
(812)-377-7255

Samuel J. Wormley
233 Applied Sciences Ctr.
Ames Laboratory
Iowa State University
Ames, IA 50011
(515)-294-7743

Loren Zachary
210 Lab of Mechanics
Iowa State University
Ames, IA 50011
(515)-294-3123

SUMMARY BUDGET PROPOSAL FY85-FY89

ORGANIZATION				Proposal No.	Duration (Months)	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR				Award No.	Proposed	Granted
Towa State University						
D. O. Thompson						
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	NSF funded person-mos.			ISU cost shared	Funds requested by proposer	Funds granted by NSF (if different)
	CAL	ACAD	SUMR			
1. A. Netusil				\$	\$ 12,500	\$
2.						
3.						
4.						
5. () Others (List individually on budget explanation page)						
6. () Total senior personnel (1-5)						
B. Other personnel (Show numbers in brackets)						
1. () Postdoctoral associates						
2. () Other professionals (technician, programmer, etc.)						
3. () Graduate students					84,000	
4. () Undergraduate students						
5. () Secretarial-clerical					28,000	
6. () Other Admin. Assist.					55,000	
Total salaries and wages (A+B)					179,500	
C. Fringe benefits (if charged as direct costs)					32,875	
Total salaries, wages and fringe benefits (A+B+C)					212,375	
D. Permanent equipment (List item and dollar amount for each item exceeding \$1,000; items over \$10,000 require certification)						
Total permanent equipment						
E. Travel 1. Domestic (incl. Canada and U.S. possessions)					11,505	
2. Foreign						
F. Participant support costs						
1. Stipends \$						
2. Travel						
3. Subsistence						
4. Other						
Total participant costs						
G. Other direct costs						
1. Materials and supplies						
2. Publication costs/page charges						
3. Consultant services						
4. Computer (ADPE) services						
5. Subcontracts						
6. Other						
Total other direct costs						
H. Total direct costs (A through G)						
I. Indirect costs (specify) Overhead costs on industrial portion of Center operating costs (estimated)				\$1,710,015		
Total indirect costs Overhead on NSF portion at 34% of direct costs					76,120	
J. Total direct and indirect costs (H+I)				\$1,710,015	300,000	
K. Residual funds (if for further support of current projects GPM 252 and 253)						
L. Amount of this request (J) or (J minus K)				\$	\$ 300,000	\$
PI/PD typed name & signature*	Date	FOR NSF USE ONLY				
		INDIRECT COST RATE VERIFICATION				
Inst. Rep. typed name & signature*	Date	Date Checked	Date of Rate Sheet	Initials - DGC	Program	

*Signatures required only for revised budget (GPM 233)

ORGANIZATION Iowa State University				Proposal No.	Duration (Months)		
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR D. O. Thompson				Award No.	Proposed	Granted	
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)				NSF funded person-mos.	ISU cost shared	Funds requested by proposer	Funds granted by NSF (if different)
				CAL	ACAD	SUMR	
1. A. Netusil (Evaluator)					0.6		\$ 2,500
2.							
3.							
4.							
5. () Others (List individually on budget explanation page)							
6. () Total senior personnel (1-5)							
B. Other personnel (Show numbers in brackets)							
1. () Postdoctoral associates							
2. () Other professionals (technician, programmer, etc.)							
3. (2) Graduate students						24,000	
4. () Undergraduate students							
5. (1/2) Secretarial-clerical						7,000	
6. (1/2) Other Admin. Asst.						12,220	
Total salaries and wages (A+B)						45,720	
C. Fringe benefits (if charged as direct costs)						7,430	
Total salaries, wages and fringe benefits (A+B+C)						53,150	
D. Permanent equipment (List item and dollar amount for each item exceeding \$1,000; items over \$10,000 require certification)							
Total permanent equipment							
E. Travel 1. Domestic (incl. Canada and U.S. possessions)						2,820	
2. Foreign							
F. Participant support costs							
1. Stipends \$ _____							
2. Travel _____							
3. Subsistence _____							
4. Other _____							
Total participant costs							
G. Other direct costs							
1. Materials and supplies							
2. Publication costs/page charges							
3. Consultant services							
4. Computer (ADPE) services							
5. Subcontracts							
6. Other							
Total other direct costs							
H. Total direct costs (A through G)							
I. Indirect costs (specify) Overhead costs on industrial portion of Center operating costs (estimated)					\$233,590		
Total indirect costs Overhead on NSF portion at 34% of direct cost						19,030	
J. Total direct and indirect costs (H+I)					\$233,590	75,000	
K. Residual funds (if for further support of current projects GPM 252 and 253)							
L. Amount of this request (J) or (J minus K)					\$	\$ 75,000	\$
PI/PD typed name & signature*				Date	FOR NSF USE ONLY		
					INDIRECT COST RATE VERIFICATION		
Inst. Rep. typed name & signature*				Date	Date Checked	Date of Rate Sheet	Initials - DGC
							Program

*Signatures required only for revised budget (GPM 233)

ORGANIZATION Iowa State University				Proposal No.	Duration (Months)	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR D. O. Thompson				Award No.	Proposed	Granted
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)				NSF funded person-mos.	ISU cost shared	Funds requested by proposer
				CAL	ACAD	SUMR
1. A. Netusil					0.6	
2.						
3.						
4.						
5. () Others (List individually on budget explanation page)						
6. () Total senior personnel (1-5)						
B. Other personnel (Show numbers in brackets)						
1. () Postdoctoral associates						
2. () Other professionals (technician, programmer, etc.)						
3. (2) Graduate students						24,000
4. () Undergraduate students						
5. (1/2) Secretarial-clerical						7,000
6. (1/2) Other Admin. Asst.						12,220
Total salaries and wages (A+B)						45,720
C. Fringe benefits (if charged as direct costs)						7,430
Total salaries, wages and fringe benefits (A+B+C)						53,150
D. Permanent equipment (List item and dollar amount for each item exceeding \$1,000; items over \$10,000 require certification)						
Total permanent equipment						
E. Travel 1. Domestic (incl. Canada and U.S. possessions)						2,820
2. Foreign						
F. Participant support costs						
1. Stipends \$ _____						
2. Travel _____						
3. Subsistence _____						
4. Other _____						
Total participant costs						
G. Other direct costs						
1. Materials and supplies						
2. Publication costs/page charges						
3. Consultant services						
4. Computer (ADPE) services						
5. Subcontracts						
6. Other						
Total other direct costs						
H. Total direct costs (A through G)						
I. Indirect costs (specify) Overhead costs on industrial portion of Center operating costs (estimated)				\$313,515		
Overhead on NSF portion at 34% of Total indirect costs direct costs					19,030	
J. Total direct and indirect costs (H+I)				\$313,515	75,000	
K. Residual funds (if for further support of current projects GPM 252 and 253)						
L. Amount of this request (J) or (J minus K)				\$ 313,515	\$ 75,000	\$
PI/PD typed name & signature*				Date	FOR NSF USE ONLY	
					INDIRECT COST RATE VERIFICATION	
Inst. Rep. typed name & signature*				Date	Date Checked	Date of Rate Sheet
						Initials - DGC
						Program

*Signatures required only for revised budget (GPM 233)

ORGANIZATION Iowa State University				Proposal No.		Duration (Months)	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR D. O. Thompson				Award No.		Proposed	Granted
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)				NSF funded person-mos.		ISU cost shared	Funds requested by proposer
				CAL	ACAD	SUMR	Funds granted by NSF (if different)
1. A. Netusil					0.6		\$ 2,500
2.							
3.							
4.							
5. () Others (List individually on budget explanation page)							
6. () Total senior personnel (1-5)							
B. Other personnel (Show numbers in brackets)							
1. () Postdoctoral associates							
2. () Other professionals (technician, programmer, etc.)							
3. (2) Graduate students							24,000
4. () Undergraduate students							
5. (1/2) Secretarial-clerical							7,000
6. (1/2) Other Admin. Asst.							12,220
Total salaries and wages (A+B)							45,720
C. Fringe benefits (if charged as direct costs)							7,430
Total salaries, wages and fringe benefits (A+B+C)							53,150
D. Permanent equipment (List item and dollar amount for each item exceeding \$1,000; items over \$10,000 require certification)							
Total permanent equipment							
E. Travel 1. Domestic (incl. Canada and U.S. possessions)							2,820
2. Foreign							
F. Participant support costs							
1. Stipends \$ _____							
2. Travel _____							
3. Subsistence _____							
4. Other _____							
Total participant costs							
G. Other direct costs							
1. Materials and supplies							
2. Publication costs/page charges							
3. Consultant services							
4. Computer (ADPE) services							
5. Subcontracts							
6. Other							
Total other direct costs							
H. Total direct costs (A through G)							
I. Indirect costs (specify) Overhead costs on industrial portion of Center operating costs (estimated)					352,619		
Overhead on NSF portion at 34% of Total indirect costs direct costs						19,030	
J. Total direct and indirect costs (H+I)					352,619	75,000	
K. Residual funds (if for further support of current projects GPM 252 and 253)							
L. Amount of this request (J) or (J minus K)					\$ 352,619	\$ 75,000	\$
PI/PD typed name & signature*				Date	FOR NSF USE ONLY		
					INDIRECT COST RATE VERIFICATION		
Inst. Rep. typed name & signature*				Date	Date Checked	Date of Rate Sheet	Initials - DGC Program

*Signatures required only for revised budget (GPM 233)

ORGANIZATION				Proposal No.	Duration (Months)		
Iowa State University					Proposed	Granted	
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR				Award No.			
D. O. Thompson							
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)				NSF funded person-mos.	ISU cost shared	Funds requested by proposer	Funds granted by NSF (if different)
				CAL	ACAD	SUMR	
1. A. Netusil				0.6		\$ 2,500	\$
2.							
3.							
4.							
5. () Others (List individually on budget explanation page)							
6. () Total senior personnel (1-5)							
B. Other personnel (Show numbers in brackets)							
1. () Postdoctoral associates							
2. () Other professionals (technician, programmer, etc.)							
3. (1/2) Graduate students						6,000	
4. () Undergraduate students							
5. (1/2) Secretarial-clerical						7,000	
6. (1/2) Other Admin. Asst.						12,220	
Total salaries and wages (A+B)						27,720	
C. Fringe benefits (if charged as direct costs)						6,920	
Total salaries, wages and fringe benefits (A+B+C)						34,650	
D. Permanent equipment (List item and dollar amount for each item exceeding \$1,000; items over \$10,000 require certification)							
Total permanent equipment							
E. Travel 1. Domestic (incl. Canada and U.S. possessions)						2,665	
2. Foreign							
F. Participant support costs							
1. Stipends \$ _____							
2. Travel _____							
3. Subsistence _____							
4. Other _____							
Total participant costs							
G. Other direct costs							
1. Materials and supplies							
2. Publication costs/page charges							
3. Consultant services							
4. Computer (ADPE) services							
5. Subcontracts							
6. Other							
Total other direct costs							
H. Total direct costs (A through G)							
I. Indirect costs (specify) Overhead on industry portion of Center operating costs (estimated)				388,881			
Total indirect costs Overhead on NSF portion at 34% of direct cost						12,685	
J. Total direct and indirect costs (H+I)				388,881		50,000	
K. Residual funds (if for further support of current projects GPM 252 and 253)							
L. Amount of this request (J) or (J minus K)				\$		\$ 50,000	\$
PI/PD typed name & signature*				Date	FOR NSF USE ONLY		
					INDIRECT COST RATE VERIFICATION		
Inst. Rep. typed name & signature*				Date	Date Checked	Date of Rate Sheet	Initials - DGC
							Program

*Signatures required only for revised budget (GPM 233)

ORGANIZATION				Proposal No.	Duration (Months)	
					Proposed	Granted
Iowa State University						
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR				Award No.		
D. O. Thompson						
A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)			NSF funded person-mos.	ISU cost shared	Funds requested by proposer	Funds granted by NSF (if different)
			CAL ACAD SUMR			
1. A. Netusil			0.6	\$	\$ 2,500	\$
2.						
3.						
4.						
5. () Others (List individually on budget explanation page)						
6. () Total senior personnel (1-5)						
B. Other personnel (Show numbers in brackets)						
1. () Postdoctoral associates						
2. () Other professionals (technician, programmer, etc.)						
3. (1/2) Graduate students					6,000	
4. () Undergraduate students						
5. () Secretarial-clerical						
6. (1/4) Other Admin. Asst.					6,120	
Total salaries and wages (A+B)					14,620	
C. Fringe benefits (if charged as direct costs)					3,655	
Total salaries, wages and fringe benefits (A+B+C)					18,275	
D. Permanent equipment (List item and dollar amount for each item exceeding \$1,000; items over \$10,000 require certification)						
Total permanent equipment						
E. Travel 1. Domestic (incl. Canada and U.S. possessions)					380	
2. Foreign						
F. Participant support costs						
1. Stipends \$ _____						
2. Travel _____						
3. Subsistence _____						
4. Other _____						
Total participant costs						
G. Other direct costs						
1. Materials and supplies						
2. Publication costs/page charges						
3. Consultant services						
4. Computer (ADPE) services						
5. Subcontracts						
6. Other						
Total other direct costs						
H. Total direct costs (A through G)						
I. Indirect costs (specify) Overhead on industrial portion of Center operating costs (estimated)				421,410		
Overhead on NSF portion at 34% of direct cost					6,345	
J. Total direct and indirect costs (H+I)				421,410	25,000	
K. Residual funds (if for further support of current projects GPM 252 and 253)						
L. Amount of this request (J) or (J minus K)				\$	\$	\$
PI/PD typed name & signature*			Date	FOR NSF USE ONLY		
				INDIRECT COST RATE VERIFICATION		
Inst. Rep. typed name & signature*			Date	Date Checked	Date of Rate Sheet	Initials - DGC
						Program

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